The George W. Woodruff
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(NASA-CR-182835) LUNAR SOIL BAGGING IMPLEMENT Advanced Missions Space Design Program (Georgia Inst. of Tech.) 119 p
N91-70298
Unclas
00/37 0279961

LUNAR SOIL BAGGING IMPLEMENT

March 1987

Georgia Institute of Technology
Atlanta, Georgia 30332

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THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

ME 4182
MECHANICAL DESIGN ENGINEERING

NASA/UNIVERSITY
ADVANCED MISSIONS SPACE DESIGN PROGRAM

LUNAR SOIL BAGGING IMPLEMENT

March 1987

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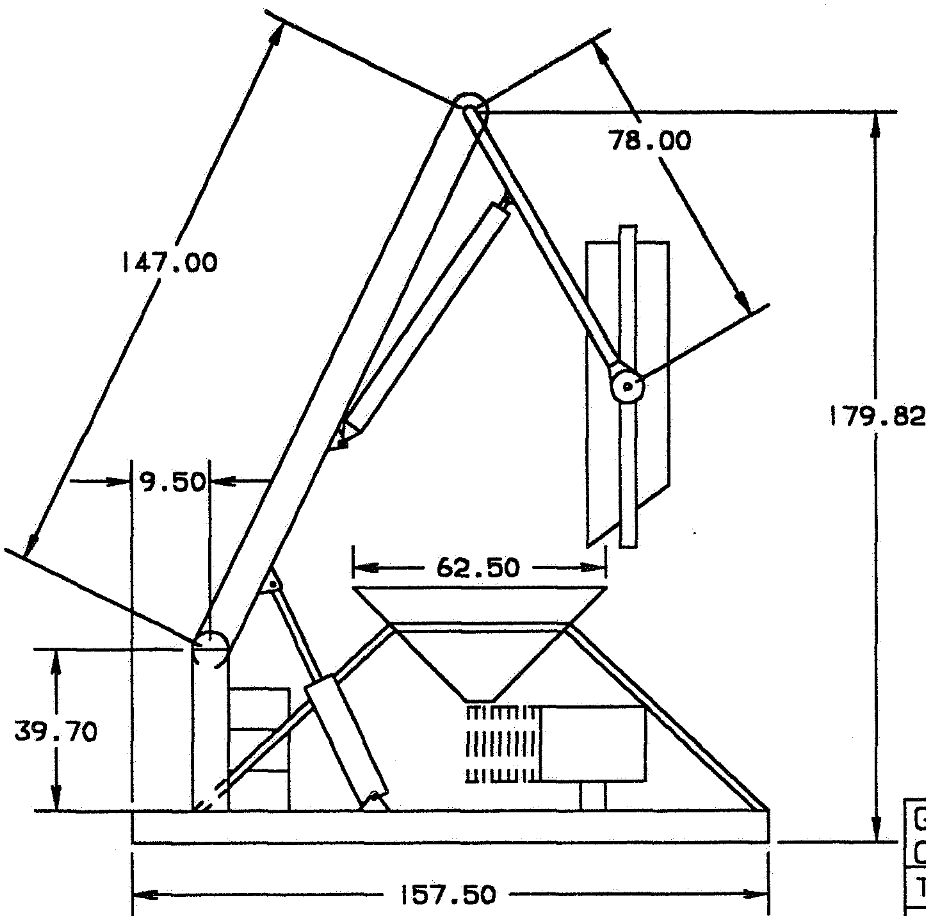

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TITLE: SOIL BAGGING IMPLEMENT	
DESIGN: JFI	DATE 10MR87
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ABSTRACT

This report details the design of a Lunar Soil Bagging Implement (LSBI). This device will, in conjunction with the proposed Lunar Arthropod, perform the task of packaging native lunar soil into bags. These bags will be used as protective covering for the various modules which will comprise the proposed Lunar Base.

There are certain design specifications which have been integrated into the design of the LSBI. Foremost among these are the limitations imposed by the lunar environment. The LSBI is designed to operate within a temperature range of -200 degrees Fahrenheit to +200 degrees Fahrenheit. Its lubricated joints are sealed in order to prevent the introduction of dust, as well as to prevent to loss of lubricant due to vacuum.

Several performance objectives were also specified, and provisions have been made for them in the design. Most notable is the requirement that the LSBI be capable ofbagging 14,200 cubic meters of soil within eighteen months. The design analysis of this requirement is provided.

The basic operation of the device is cyclic. The native soil is removed from the surface by a hydraulic-actuated scoop mechanism, which is in turn lifted to a position which allows the soil to be dumped in a hopper. The soil then drops into the bags as they pass beneath the hopper in an incremental fashion. The bags are dispensed from a roll, one edge of which is a continuous Ziploc seal. As each bag moves into position beneath the hopper, filled bags are closed by the same action, whereupon they are severed from the roll by a laser and deposited on the lunar surface. There are only four powered actions to the entire process - a hydraulic lifting arm, a positioning motor for the scoops, a hydrauic arm to position and close the bags, and a laser to sever each filled bag.

PROBLEM STATEMENT

NASA has proposed that the living and working quarters for the Lunar Base will be prefabricated modules which will rest on the lunar surface in a largely exposed manner. These modules will require more protection from the lunar environment than that which will be provided for in their construction, since to include sufficient protection would have drastic effects on the mass of the units to be transported, as well as their cost. It is far more practical to protect the modules by covering them with native lunar soil. It has been postulated that a two-meter thickness of soil will be sufficient to protect a module from any meteorite activity, and will also aid in insulating the module, and that "sand-bags" will be the most efficient means for the disposition of the soil.

The problem is, therefore, to design an implement for the proposed Lunar Arthropod which will remove soil from the lunar surface, package it into bags, and return these bags to the surface. This device must be capable of operating in the lunar environment for extended periods of time without human supervision or control. It must also be able to provide sufficient soil within an eighteen month period to cover a single module. Target parameters for the design are to minimize both the mass and power consumption of the implement, as well as to provide for ease of maintenance.

More peripherally, the implement must be designed to interface with the Lunar Arthropod, using for this interface a standardized assembly which will be common to all other implements for the Arthropod.

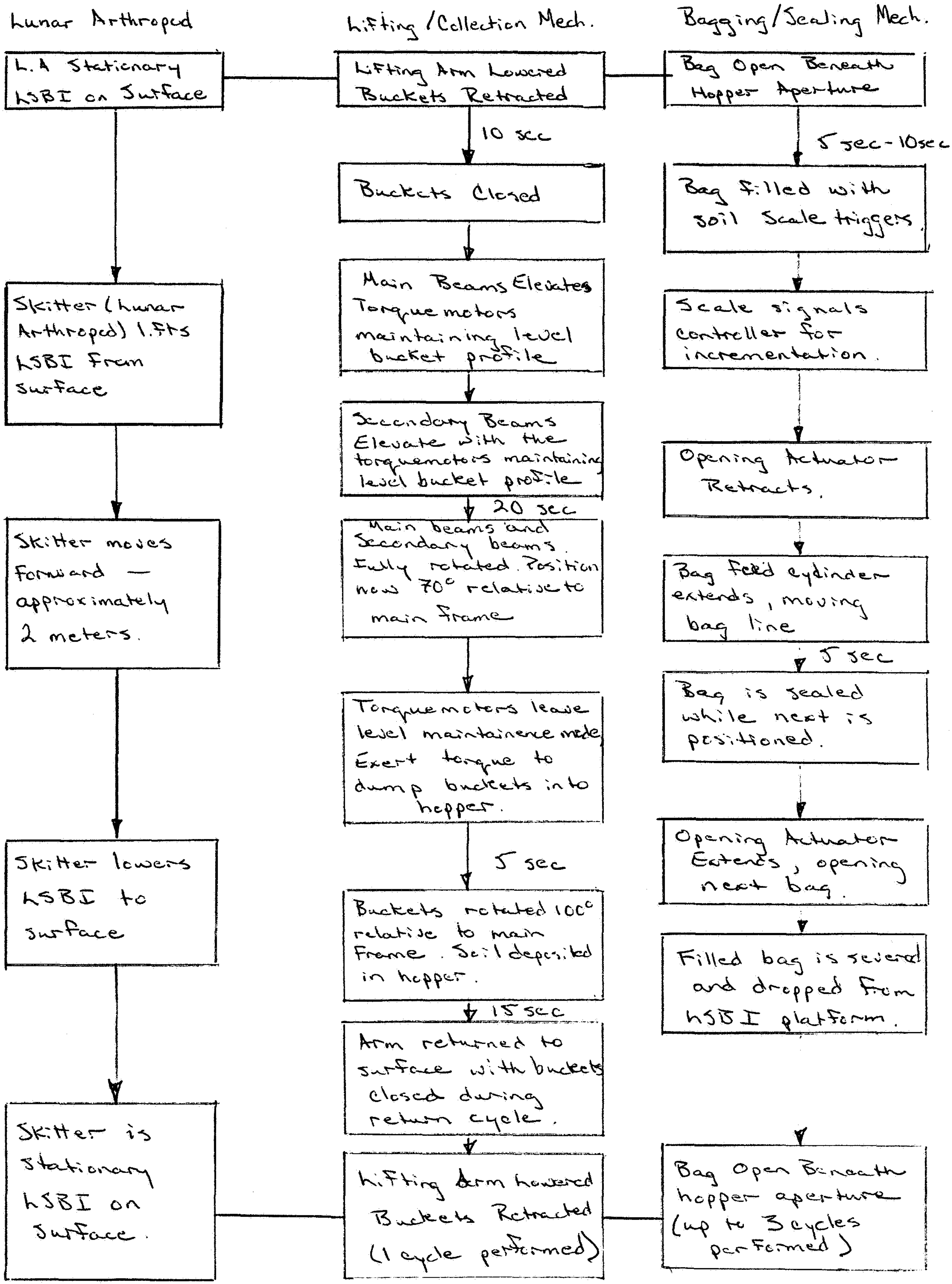
DESCRIPTION

The Lunar Soil Bagging Implement is a device which is to be used in conjunction with the proposed Lunar Arthropod. Its purpose is to manufacture bags of soil on the lunar surface. The LSBI is designed to produce these sandbags, which are to be used as protective covering for the modular living and working quarters of the proposed Lunar Base, in sufficient quantity that each module can be covered to a uniform minimum thickness of two meters in eighteen months. The unit is self contained, using fuel cells as its independent power source, and can be attached to the Lunar Arthropod by a single standard interface connection.

The LSBI operates in two stages. First, there is a loading and feeding mechanism which removes soil from the lunar surface and transfers it to a hopper. From that point the bagging and sealing mechanism packages the soil into 0.06 cubic meter teflon bags and seals them by means of a continuous Ziploc seal. The bags are then deposited on the lunar surface for deposition by unspecified means.

Quantitatively, the LSBI is capable of producing 0.90 cubic meters of packaged soil per minute, or 6 filled bags. Each scoop of soil removed from the surface amounts to the equivalent of 3 filled bags, or 0.45 cubic meters. The LSBI can process 2000 bags per roll of bags provided, with little or no maintenance time required in the interim.

SYSTEM FLOW CHART



ANALYSIS

The design of the LSBI is essentially a two-fold problem. First, there is the design of the scooping and feeding mechanism. Second, there is the design of the bagging and sealing mechanism. The analysis of the LSBI design has, therefore been resolved into these two parts. There are, however certain aspects of the overall design which require joint discussion. There is also the problem of the interface design, which has been standardized for all implements of the Lunar Arthropod. This analysis, as well as any details of the LSBI design which are pertinent to both principle assemblies, will be discussed after the designs of the individual assemblies are discussed.

COLLECTION PROCESS ASSEMBLY

SYSTEM ANALYSIS

The collection and feeding mechanism of the LSBI is a linkage system controlled by a microprocessor control system. Referring to the figure in Appendix I, the overall concept of the mechanism can easily be inferred. The mechanism itself is comprised of four primary components - the bucket assembly, the lifting arms, the pivot links, and the hopper. All, with the exception of the latter two, require an individual motive source. Each of these structures and their motive sources are detailed in this design.

The arrangement of the collection process assembly's mechanical components can basically described as follows:

(1) The bucket mechanism is comprised of a rectangular frame which holds two sliding bucket-halves on lateral tracks. The buckets are opened (retracted) or closed (extended) by means of four hydraulic actuators (one cylinder at each of the four corners of the frame). The entire assembly is joined at its lateral centrode axis to the lifting arm mechanism. This juncture is accomplished using two positioning electric torque-motors, each of which allows the bucket assembly a full 360 degrees of rotation, relative to the lifting arms. (Refer to figure in Appendix I).

(2) The lifting arm is a four segment beam assembly which links the bucket assembly to the pivot link. The main beams (2), attached to the pivot links (2) is allowed a 58 degree motion relative to the frame; and are powered by twin hydraulic cylinders which are affixed to the main frame of the LSBI. The secondary beams (2) are smaller lengths which join the main beams to the bucket mechanism. Each is powered by a hydraulic cylinder which links the two beams (refer to Appendix I).

(3) The pivot link joins the main beam to the main frame of the LSBI and is essentially an elevated joint.

(4) The hopper is fixed in position and is placed over the bagging and sealing mechanism.

The overall motion of the collection mechanism can be most easily described by referring to the system motion flow chart This flow chart covers one complete cycle of the LSBI, in coordination with the Lunar Anthropod. It is noted that, for purposes of this examination, the elapsed time for the various stages of the cycle are given, but are by no means fixed or mandatory. These values were chosen in order to minimize power consumption while remaining within the production time table specified.

PERFORMANCE ANALYSIS

The LSBI will have certain production guidelines to meet, and therefore, some idea must be given as to its performance. This evaluation will be based on estimated conditions for its use, with accommodations being allowed for reasonable deviation from these estimates.

As the problem for the design of the LSBI was set forth originally, it was stated that 2475 cubic meters of bagged soil would be required within an 18 month period. this demand value must be adjusted for such factors as the availability of the Lunar Anthropod, down-time due to maintenance, travel time to a suitable location, etc. By assigning reasonable values to each of these production-limiting factors, the problem reduces to that of producing 0.0566 cubic meters (2 cubic feet) of bagged soil per minute. The LSBI was designed with an overall safety factor of 2, both in construction and operation, so its performance is evaluated requiring 0.1133 cubic meters (4 cubic feet) per minute. This performance evaluation is summarized as follows:

	Energy Required	Time Allowed	Power Required
Bucket Rotation (total cycle)	20 N-m	10 sec	2.0 watts
Bucket Closure/Opening	1100 N-m	20 sec	55.0 watts
Total Arm Swing	2400 N-m	20 sec	120.0 watts

Total Collection Process Energy Required: 3520.0 N-m
Total Collection Process Power Required: 177.0 watts

STRUCTURAL ANALYSIS

BUCKETS

The buckets for the collection process mechanism of the LSBI are polyheral forms constructed of sheet A97175 aluminum alloy. Essentially, these shapes of a rectangular box which have been modified to allow a lessened angle of tilt to be neccessary to empty the buckets of soil. By reference to Appendix C, page C-3), the exact configuration of the bucket halves and their orientation within the supporting frame can be seen. Each of these buckets is formed of sheets 5mm in thickness. The buckets are suspended within the frame by a pair of lateral rails or tracks which serve also to align the scoops during closure and opening. The buckets travel on the rails in eased by the implementation on rollers which are affixed to the buckets. It is found that the force neccessary to drive the buckets through the soil, while scooping amounts to a total of 8240 N. The structure of the buckets is preserved during their closure by means of support brackets of aluminum tubing which are mounted longitudinally on the buckets themselves. Refer to Appendix D for a complete examination of the buckets and their supporting apparatus.

Main Beam

The main beams are the primary structural members of the lifting arm mechanism. They are constructed of the 75 series Aluminium alloy with dimensions in accordance with Figure 1 page D-1. The beam has a mass of 0.9 kg per linear meter at these cross-sectional dimensions. All calculations for the main beam can be found in Appendix D.

The maximum forces exerted on the main beam are calculated using a 6 inch soil thickness per cycle. This generates a total bucket load of 150 N per arm. The maximum forces on the main beam, therefore, are a maximum shearing force of 600 N, concentrated at a point between the pivot end of the main beam and the point of juncture between the main beam and its hydraulic actuator. This force occurs at the fully lowered position of the lifting arm upon attempting to lift.

The maximum axial force, occurring under the same conditions as the maximum shear force, is 200 N. The maximum moment is 300 N-m and occurs at the point of the main hydraulic connection.

Secondary Beams

The dimensions and configurations of the secondary beams can be easilyseen in Figure 1 on page D-1. These beams are smaller since the forces on them--particularly the moment loads, are not as large as those on the main beams. The maximum forces on these secondary beams are, in fact, a maximum moment load of 60 N-m, a maximum shear force of 90 N, and a maximum axial load of 220 N. Again all calculations can be found in Appendix D on page D-2.

These beams are also constructed from the 75 Aluminum series. The juncture between the main beam and the secondary beam will be a sealed elbow joint lubricated with molybdenum disulphide.

Pivot Link

The pivot links are essentially, elbow joints which are elevated from the main frame of the LSBI in order to gain a mechanical advantage. This link will, however, undergo the largest force--loading of the entire lifting mechanism. It will, therefore, require either larger cross-sectional dimensions or a lessened safety factor. Since the safety factor applied to the main beams was intentionally made overly large, due to the wide range of possible loading conditions, its dimensions will suffice for the pivot link.

The maximum loads applied to the pivot links are largely due to the momentum area which is formed by the elevation of the pivot joint. These forces are as follows: a maximum moment of 230 N-m, a maximum shear force of 220 N, and a maximum axial force of 600 N. Calculations of these forces are contained in Appendix D.

So far as the design of the actual joints of the lifting mechanism, both pivot and that of the main/secondary beam juncture have been left largely undetailed. Other than the beam interfaces and the obvious fact that the joints must be sealed and preferably utilize a non-volatile lubricant such molybdenum disulfide. This lack of detail is due to the constant development of various new flexure joints as well as improved bearing-joint mechanisms. It is assumed that an ideal joint will be appended to this design. Also, it sould be noted that NASA is presently conducting exhaustive research in this area.

Hopper

The hopper is the repository for collected soil after it is dumped from the bucket. It is constructed of 5 mm thicksheet

Aluminum alloy (75 series). In shape, it is an inverted truncated right circular cone with an upper diameter of 1.8 m; a lower diameter of 0.2 m; a height of 0.2 m; and a 45 degree declination. Filled to an even flat profile, it holds a volume of 0.8 cubic meters of soil with a total weight of 150 N. (Refer to figure on page D-22).

The hopper is topped with a conical screen of reinforced aluminum mesh. This mesh is an arrangement of 5 cm square apertures designed to limit the size of soil and rock particles admitted to the hopper. The mesh is composed of the 75 series Aluminum alloy and has a 1 mm thickness which is reinforced by 10 mm aluminum strips.

The supports for the hopper are circular cross-section tubular members with an outer diameter of 3.1 cm. and a wall thickness of 0.32 cm. They are oriented with 70 degree angle between each leg and the main frame, in order to allow more working space on the surface of the frame.

WEIGHT/MASS/INERTIA ANALYSIS

The total weight of the collection process is composed of: (1) the weight of the soil; (2) the weight of the bucket structure; (3) the weight of the lifting structure; and (4) the weight of the hopper structure. Each component is summarized in the chart on the next page with their respective weight contribution.

	Weight (N)
Soil per Load & Bucket	150
Lifting Structure	662
Hopper Structure (loaded)	150

FAILURE ANALYSIS

An overall safety factor of 2 was used for determining the structural design. In the case of calculating the loading effects on the mechanism, the worst case was considered.

Due to environmental conditions, possible defects in the seals at the joints could result in failure of lubricants. Another possible area of failure could be at the pivot joint. As the pivot undergoes a cyclic stresses, fatigue failure is another concern.

BAG FASTENING PROCESS ASSEMBLY

SYSTEM ANALYSIS

The bag filling and fastening process involves the most complex motions required for the LSBI, so it will, of course, neccessitate the use of more individual components. The process will center around the performance of certain operations in the proper order, with this control being supplied by a microprocessor control system. The essential components of the assemply are the hopper, a roll of pre-fabricated Teflon bags, guide and support tracks, an opening mechanism, a sealing mechanism, a scale, a hydraulic arm to pull the bags along, and a laser to sever each filled and sealed bag as it reaches the rear of the LSBI. The actual arrangement of process components is as follows:

(1) The hopper, detailed in the Collection Process analysis, is shown in the figure on page D-23. The soil is supplied to the bag assembly from its lower aperature.

(2) Teflonbags will be pre-fabricated for this operation. Each bag is 0.457 m in height, 0.457 m in width, and 3 mm (approximately one-eighth inch) in thickness. Each bag will be sealed by means of a Ziploc seal which will form a continuous edge on one side of the roll of bags. The roll itself will have an outer diameter of 1 m and an inner (shaft) diameter of 5 cm. This will allow each roll to supply approximately 2000 bags before a new roll is required. The bags will be formed by a 3 cm segment of the bag material which wil be bonded together between segments, and this will also serve as the detachment line for each bag. The first few meters of the roll will be unsegmented to allow initial loading and feeding of the bagging mechanism.

(3) The bagging assembly implements guide and support tracks to control the progression of bag material through the system. These tracks are composed of 75 series Aluminum and are 2 mm in thickness and 2 cm in height. Each bag will slide, suspended from the tracks by grooves on the outer surface of the Ziploc seal.

(4) An opening and closing mechanism is required in order to spread each bag open as it is positioned beneath the hopper structure. This device was designed using the elastic buckling concept which was rejected as a means of sealing individual bags. (Refer to Appendix B). After each bag is positioned beneath the hopper, a hydraulic cylinder is extended which

spreads open two thin stainless steel bands which are joined end to end and left unfixed between the ends. This spreads open each bag to allow it to fill with soil. Once the bag is filled, the hydraulic cylinder retracts and the bag is closed.

(5) A scale is needed to increment the bag fastening process once a bag has been filled with soil. The scale is positioned beneath the bag being filled with soil such that initially the empty bag rests upon the scale. As the bag fills, the scale monitors the weight of the bag and soil so that once the bag is filled, the control system is alerted, the next bag is moved into position, and the filled bag is sealed.

(6) The sealing mechanism is a pair of pinch-rollers, 4 cm in diameter, which are positioned so that as the bag is moved from under the hopper aperature and off the opening mechanism, its seals are pressed together and closed.

(7) The bags are pulled through the fastening system by a hydraulic cylinder which utilizes a clamp to seize the filled bags and pull them to the rear of the LSBI. In doing so, the empty bags are also pulled from the supply roll.

(8) A laser knife is used to sever each filled bag as it is removed from the sealing system and leaves the guide tracks. Located above the line of bags and directed downward, it requires a minimum arc to sever each bag completely.

The motion of the bagging and fastening system is most easily understood by study of the LSBI System Flow Chart (page 4) which follows the system through one complete cycle.

PERFORMANCE ANALYSIS

The performance of the bag filling and fastening process assembly is best judged in terms of three factors: its conformance to the production objectives which were set forth originally; its energy demands on the entire LSBI system; and its maintenance requirements--most notably, how many bags can be processed without human personnel being required to load the roll into the system.

It was set forth that the LSBI must produce enough soil in 18 months to cover a single base module to a thickness of 3 m. This amount, corrected for all availability factors, reduces to a required production rate of 0.0566 cubic meters of soil. The design of the LSBI was performed with an overall safety factor of 2--meaning that the assumed requirement were for 0.1133

FAILURE ANALYSIS

As in the collection process assembly, an overall safety factor of 2 was used for determining the bag fastening design. Possible conditions for failure exist at the hydraulic cylinders as well as at joints due to the environmental conditions imposed on the lunar surface. Refraction of the laser beam due to dust particles is another consideration of failure. Finally, the scale must also be considered in that soil could jam this device making it malfunction.

POWER TRANSMISSION

The LSBI employs both electric and hydraulic actuators to power its motion. The collection mechanism utilizes four separate hydraulic cylinders to perform the lifting of the arm, along with four additional hydraulics to perform the closure of the scoop mechanism. The scoop mechanism also requires two positioning electric torquemotors to keep the bucket level during the motion of the lifting arm, as well as to dump the soil into the hopper at the top of the lift. The bagging and sealing mechanism employs an additional two hydraulic cylinders - that which drives the opening and closing mechanism, along with that which feeds the bags through the system. A final means of power transmission within the LSBI is the laser which is used to detach finished bags of soil from the "production line".

Since the fuel cells which supply all motive power to the LSBI are electrical sources, there is no need to convert the power used by the electric torquemotors or by the laser, since they can utilize electric power directly. In the case of the hydraulic cylinders, howeever, it is neccessary to convert this electric supply into a more usable form, hydraulic pressure. This is accomplished by the operation of an electric hydraulic pump which will a supply hydraulic pressure of 750 psi. This will operate all the hydraulic cylinders contained in the LSBI design.

A brief list of the hydraulic cylinders required and their sizes is as follows:

CYLINDER	FORCE REQUIRED	DIAMETER
MAIN LIFTING ARM (2)	700 N (x 2)	2.54 cm
SEC. LIFTING ARM (2)	220 N (x 2)	2.54 cm
BAG OPENING / CLOSING	31.25	0.159 cm
BAG MOVEMENT	50.0 N	2.54 cm

A more detailed examination of the forces required for the various hydraulic cylinders, the required sizes, etc. can be found by reference to Appendix E, page E-1.

CONTROLS

The LSBI will be controlled in its overall motion and operation by a centralized microprocessor. This microprocessor will coordinate the motions of the scooping, lifting, bag opening, and bag feeding hydraulics (refer to page E-5, Appendix E). It will also regulate the positioning of the bucket torque motors so that they remain level during the loading motion of the lifting arm. Finally, the microprocessor will control the firing and rotation of the bag-detachment laser as each bag is moved.

The exact programming and connections of this microprocessor have not been finalized. Appendix E details certain aspects of the hydraulic controls necessary.

HAZARD

There are certain hazards to be considered concerning the operation of the LSBI. Its mechanism utilizes certain components which, under any circumstances, are capable of causing unintended destruction. There are also certain features of its operation which might be dangerous.

The laser which is used to sever each bag after it has been filled and closed is, by neccessity, a very powerful one. Since its purpose is to cut through very tough material, it must be kept in mind that the lasers supports must be kept fixed and properly oriented, so that it does not "break loose" and fire uncontrolled, causing unpredictable damage.

Care must also be taken that any human personnel, if any, who will be working in close proximity to the LSBI take care that they are not beneath the lifting mechanism as it returns from the hopper, since it has no allownace for such obstacles being in its path.

There is also the possibility that there will be certain amounts of flying debris in the vicinity of the LSBI as it operates. Care should be taken to avoid such debris.

INTERFACE MECHANISM

Part of the original problem statement was that the LSBI possess a interfacing device which was standardized, allowing all implements which will be used in conjunction with the Lunar Arthropod to use the same connections. The interface for the LSBI will join with the Arthropod on the lower triangular face. This face is an equilateral triangle with sides measuring 3.5 meters each.

The interface was designed in agreement with several other design groups. It was desided to use a pin-and-socket arrangement (see figure, page G-1). The interfacing plate shown in the figure will possess three pins of triagonal profile which will join with corresponding sockets on the lower surface of the Arthropod. These pins will be fabricated from 2014 T6 Aluminum, with the dimensions as shown. The sockets will lock upon entrance of the pins, and held until release is effected by means of an electric solenoid.

The interface plate will be linked to the main frame of the LSBI by means of an assembly of fixed beams. Refer to page G-2. These beams will be af the links specified in the figure shown.

MAIN FRAME

The main frame of the LSBI will be comprised of beams of the 75-series aluminum of the following dimensions: height - 20.3 cm, width - 15.25 cm, thickness - 0.63 cm. These beams will be arranged into a 4 meter by 3 meter platform, upon which will rest the entire LSBI system, and to which the interfacing beams will be affixed.

CONCLUSIONS

The design of the LSBI involved a great many uncertain factors. Some of these were so hard to examine that additional information will have to be acquired at a later time. Such considerations as cost and exact process selection are so far in the future at the time of this design that essentially no accuracy can be achieved by attempting to isolate them at the present date.

The most elusive of the problems encountered in the design of the Lsbi was the nature of the bag-sealing mechanism. Once this had been selectied, there still remained the selection of such items as a laser of sufficient wattage to perform the cutting task designated. The exact design and totally unpredictible cost of such a laser alone can easily undermine the validity of any cost analysis, since the advancements in said field are continuous.

It can essentially, be concluded that this design for the LSBI will perform all the tasks set forth in a satisfactory manner. It must also be stated that a certain re-examination of the design will be neccessary on a periodic basis up to such a time as the LSBI is to be put into production.

RECOMENDATIONS

There are certain aspects of the LSBI design which may require additional consideration, due to a variety of reasons. The mechanism of such a device is very complex, involving a great deal of advanced technology. Since advancements are constantly being made in all areas, particularly in such areas as power transmission, microprocessor technology, and laser design, a periodic review of this design should be performed up to such a time as the design goes into production. Also, due to time considerations, certain areas of the design have been completed to greater or lesser degrees than have others.

The type and programming of the microprocessor control system which will coordinate the motion and operations of the LSBI have been left largely unspecified, although all parameters affecting their selection are provided. It is suggested that these items be studied further.

The exact type of laser which will be used to sever bags as they are processed has been given as a 500 watt argon laser, yet it is expected that advancements in the field will result in the substitution of a more efficient and suitable model.

Concerning operation of the LSBI, it is recommended that it be shipped in two segments (minimum). these segments being the collection mechanism (including the main frame) and the bagging mechanism. Since the two are actually largely independent of one another, this should allow an increase in available space per shipment.

ACKNOWLEDGEMENTS

The Lunar Soil Bagging Implement design group would like to thank the following individuals for their aid and assistance in the various aspects of designing the LSBI:

H.L. Johnson, Ph.D; Georgia Institute of Technology

Harvey Mallory; Dupont Corporation

Exotic Metals, Incorporated; Long Island, New York

Brice Mc Larin; Georgia Institute of Technology

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APPENDIX A

MATERIALS:

(I)<u>**BAG:**</u> Referring to the Bag Material Design Matrix (page A-2) it is noted that four different materials were considered for the design of the bags to be used. the reasons for their elimination or retention are given as follows:

(a)PLASTICS: This entire category of materials was eliminated from consideration due to the fact that no plastic was found which could withstand a temperature of less than -50 degrees Fahrenheit.

(b)POLYESTER: Again, the material was rejected because it will not withstand -200 degrees Fahrenheit.

(c)GLASS FIBERS: This material meets all requirements, and is retained for consideration, although flexibility is a problem as well as the attachment of sealing devices.

(d)TEFLON: This material meets all requirements with no obvious shortcomings.

(II)<u>**STRUCTURAL:**</u> There were five primary structural materials examined. The reasons for their retention or rejection are as follows:

(a)ALUMINUM: The entire 75-series of aluminum alloys meets all design requirements.

(b)BORON-EPOXY COMPOSITE (AS-4): This material seems very promising, but due to a lack of available information, it will probably not be implemented in the LSBI design.

(c)CARBON STEEL: This material does not have suitable consistancy of mechanical behavior over large temperature ranges.

(d)NICKEL-ALUMINUM "SUPER-ALLOYS": These alloys meet all design requirements, except for their comparitively high mass.

(e)STAINLESS STEEL: This material has excellent consistency of behavior over wide temperature ranges, but is of extremely high mass.

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DESIGN MATRIX FOR BAG MATERIAL

	BURST STRENGTH	RADIATION	TEMP.	FLEXIBILITY	CAN A SEAL BE ATTACHED?
PLASTICS	1	1	1	0	0
PLYESTER	1	0	1	0	0
GLASS WOVEN FIBERS	1	0	0	0	1
TEFLON FIBERS	1	0	0	0	0

KEY: 1 PRIMARY CONSIDERATION
0 NON " "

AS-4 Specs

TABLE 5. ENGINEERING CONSTANTS OF ORTHOTROPIC MATERIALS

MAT'L	Description	E_1 in 10^6 psi	E_2 in 10^6 psi	ν_{12}	G_{12} in 10^6 psi
Delta wood	Hot pressing of and stack impregnated with resin	4.27	0.66	0.13	0.31
Plywood	Plywood is assymetric but approximated by	1.69	0.86	0.08	0.09
Paper	White patent coated kraft paper	0.66	0.19	0.31	0.21
Paper	Bleached kraft paper	0.49	0.25	0.24	0.23
Paper	Food board (Continental Forest Ind.)	0.33	0.12	0.29	0.11

TABLE 6: Unidirectional Properties of Composites (Ref. 3)

composite

Property	Composite			
	AS/E	HMS/E	S-G/E	KEV/E
Long. strength, ksi	213.7	152.6	192.3	186.0
Transverse str., ksi	10.4	2.9	11.2	4.1
Interlam. Shear. Str., ksi	13.0	6.5	10.7	6.5
E_1, 10^6 psi	18.20	26.50	6.95	11.20
E_2, 10^6 psi	1.28	0.95	2.17	0.80
G_{12}, 10^6 psi	0.600	0.779	0.644	0.410
ν_{12}	0.32	0.25	0.30	0.44

BRIAN! PLEASE WRITE THESE TWO PAGES AGAIN IN A READABLE WAY!

(III) Lubrication

Due to lunar conditions, a dry lubricant is neccesitated because of the following inherent properties:

good adhesion
great temperature range
low flammability
low complexity

The dry lubricant, Molybdenum Disulphide, has the best properties, ~~and~~ therefore it was chosen over the others such as graphite, or PTFE. Graphite wasn't used due to it's poor performance in a vacuum. PTFE was eliminated due to it's poor load carrying capabilities and high wear rate. Basically, Molybdenum Disulphide is the superior choice due to the following characteristics:

low friction - 0.03 to 0.2 depending on load
Maximum PV probably about 100,000 psi x ft/min
Excellent adhesion
Excellent temperature range - -200°C to 350°C in air
Excellent performance in vacuum - temperature limit in vacuum = 1000°C
High load carrying capacity

Molybdenum Disulphide has also been extensively used in spacecraft especially the Apollo Lunar Module.

Ti 6% AL 4% Vanadium → "Grade 5 Titanium"

→ ½ wt. of Stainless Steel.

Temperature ✓
Radiation ✓
Corrosion ✓
Strength ✓

Density 0.56 lb/in³.

→ Most widely used material in Aerospace.

Specifications being mailed.

Nickel Based Superalloys

Aluminum alloys

→ Specs being mailed.

AS-4 Boron Reinforced Epoxy Composite.

→ 5 plies. of 0.05" layers.

layer 5 — 45°
layer 4 + 45°
layer 3 · 0°
layer 2 + 45°
layer 1 — 45°.

Compression strength = 290 000 psi
w/ 45° oriented layers in tension.
~~Long strength~~ = See specs Attached.

→ Kevlar -29 (cables)

65% higher breaking strength per C.S. Area than steels.

Better strength/weight than steels.

5 times strength of steel

10 times stronger than alum

APPENDIX B

BAG-FASTENING PROCESSES:

Referring to the Bag-Fastening Process Design Matrix (page B-2) it is noted that ten different bag-sealing methods were examined. The reasons for the retention or rejection of each method is as follows:

(a)ADHESIVES: This method was rejected due to the fact that adhesives will lose their volatile substances in a vacuum-environment.

(b)DRAWSTRINGS: This method was rejected due to the complexity of the mechanism which would be neccessary to perform it, as well as the fact that it would neccessitate individual positioning of each bag.

(c)ELASTIC BUCKLING: This method was rejected as a method for closing individual bags for the same reasons as method (b), yet the concept of the device was retained for consideration for the bag-filling device.

(d)COLD-WELDING: This method was eliminated for the same reasons as was method (b).

(e)ZIPPERS: This method was rejected for the reason that it involves a great deal of complexity in the closure device.

(f)ZIPLOC: This method meets all design requirements, yet some sort of protection must be provided for the seals themselves, since it is possible for dust to interfere with closure.

(g)VELCRO: This method is a possibility, although the multilateral burst strength of such seals is questionable.

(h)MECHANICAL FASTENERS: This method was rejected due to the complexity of the fastening device(s) neccessary, as well as the ease of the failure of the methods involved.

(i)SEWING: This method was rejected due to the same reasons as method (h).

	BURST STRENGTH	FLEXIBILITY	RELIABILITY	VACUUM COND.	HEAT TRANSFER	DUST SENSITIVITY	MECH. COMPLEXITY
ADAESIVES	0	0	1	1	0	1	1
DRAWSTRINGS	1	0	1	0	0	0	1
ELASTIC BUCKLING	1	1	1	0	0	0	1
COLD WELDING	1	0	1	0	1	1	1
ZIPPERS	0	1	1	0	0	1	1
ZIPLOC	1	1	1	0	0	1	1
VELCRO	1	0	1	0	0	0	1
MECH. FASTENERS	1	1	1	0	0	0	1
SEWING	1	0	1	0	0	0	1
HEAT SEALING	1	0	1	1	1	0	1

BAG FASTENING PROCESS DESIGN MATRIX

0 : IRRELEVANT

1 : RELEVANT

APPENDIX C

PRELIMINARY DESIGNS

The process which lead to the final proposed design of the LSBI resulted in a number of preliminary ideas, concepts, and actual designs. These designs were carried to varied degrees of completion before being discarded in favor of improvements. It is entirely possible that some of the ideas involved in these designs may be of use in future review of the design, and for that reason they have been included here, albeit in little detail. Each is listed by "PD-" and a reference number.

(I) LOADING/FEEDING MECHANISM:

PD-1: Refer to page C-2. This design implemented a four-bar mechanism to maintain a level load while lifting soil to the hopper. It was abandoned for the reason that its motion required unreasonable power consumption due to the positioning requirements for hydraulic actuators.

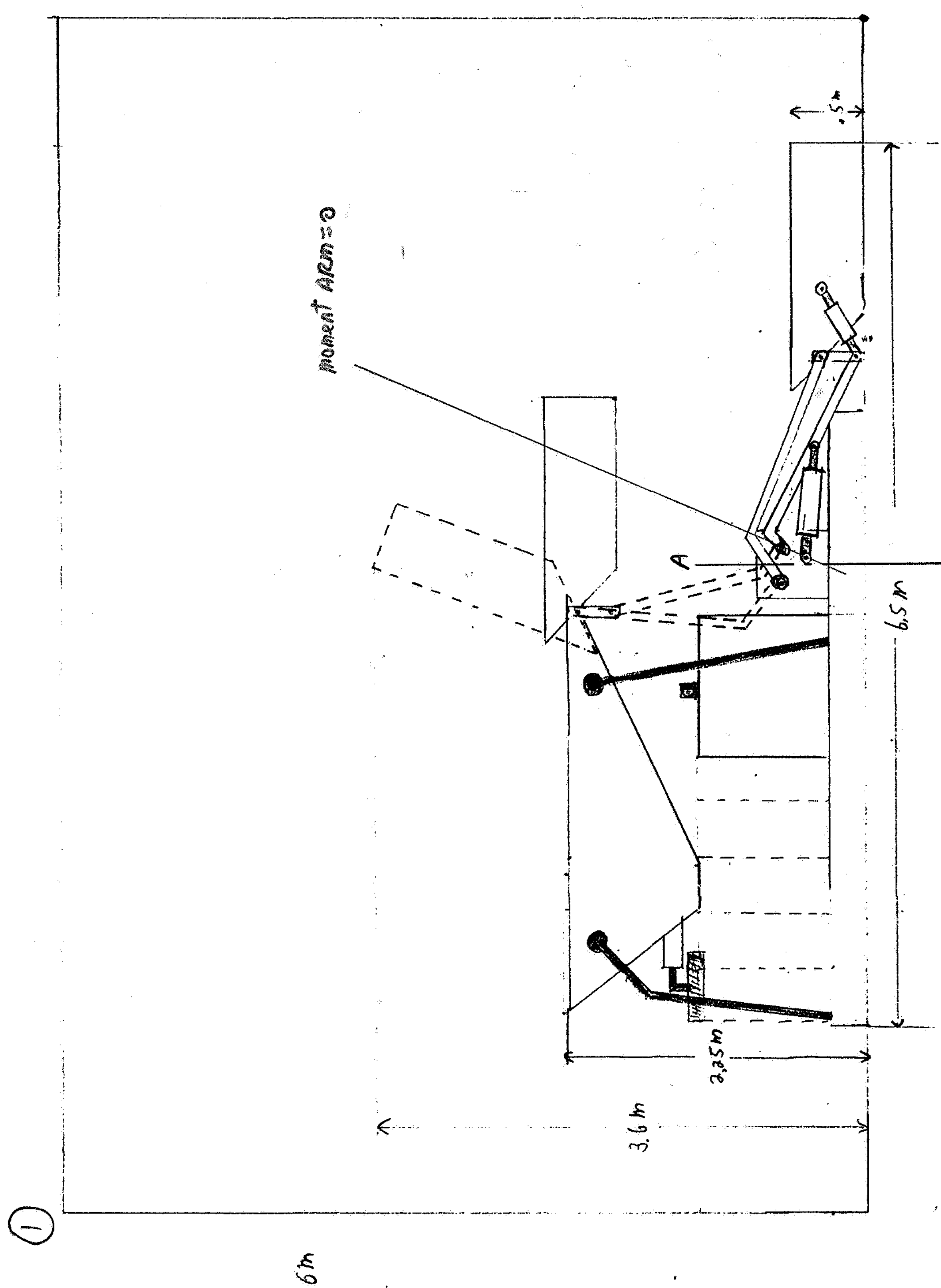
PD-2: Refer to page C-3. Improvements made to bucket control mechanism. This improved soil loading, yet hydraulic-arm positioning remained prohibitive.

PD-3: Refer to page C-4. This design eliminated the problems with multi-axial loading which were inherent in the four-bar design, yet the angle of rotation required for the loading arm was too large for effective positioning of hydraulics.

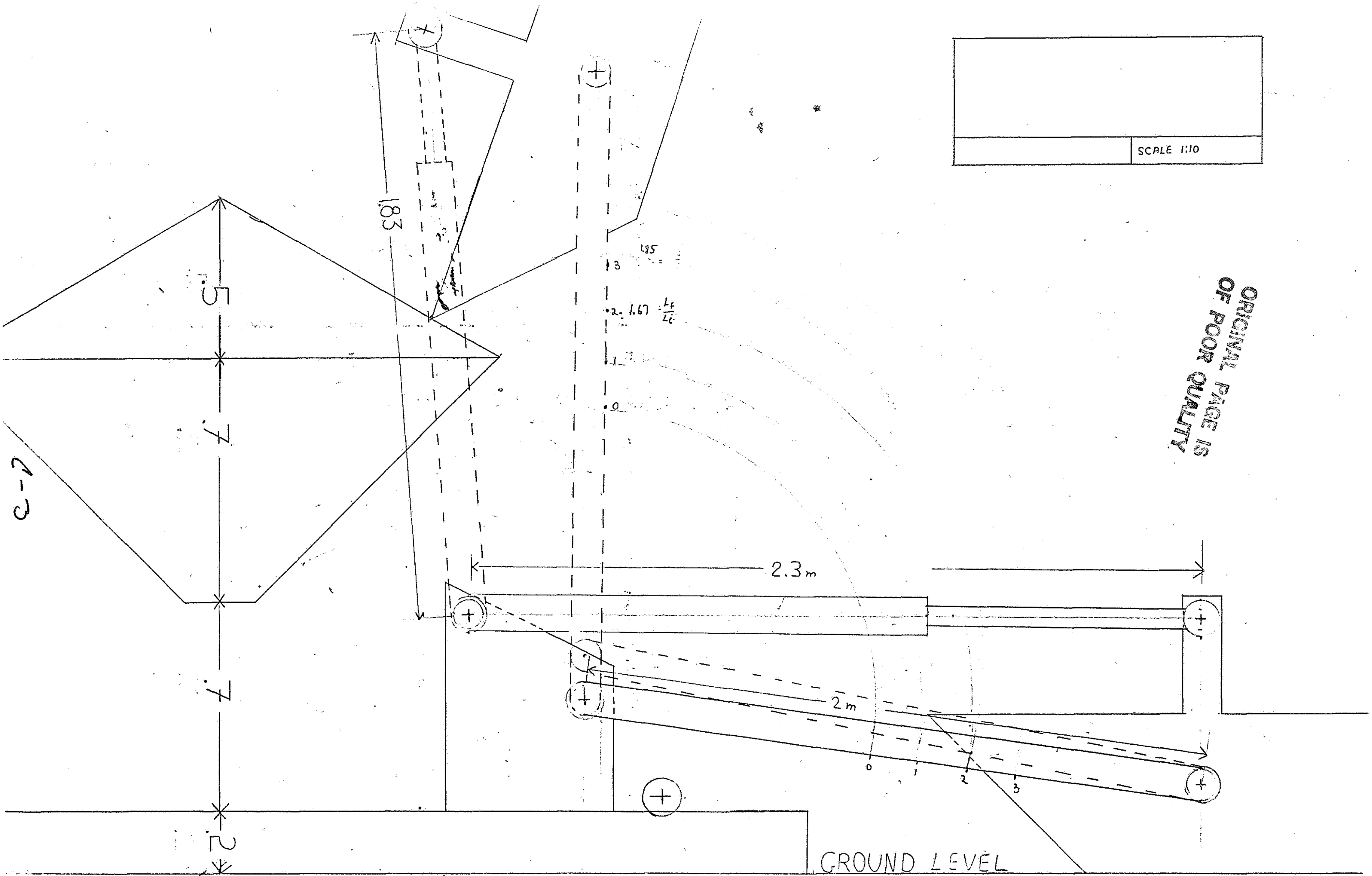
PD-4: Refer to page C-5. Alterations were made in the bucket/scoop mechanism. Rather than utilizing the originally proposed "scissor-action", the scoops were attached to a fixed frame, with four hydraulic cylinders to position them.

PD-5: Refer to page C-6. The loading arm was raised to allow for a longer hydraulic arm. This produced a more acceptable length-ratio between the fully-compressed and fully-extended positions of the cylinders.

PD-6: Refer to page C-7. The pivoting point for the loading arm was moved to the rear of the implement platform. This lessened the angle of swing required. The loading arm was also broken into two segments, allowing a improved mechanical advantage and a wider choice of scoop-positions.



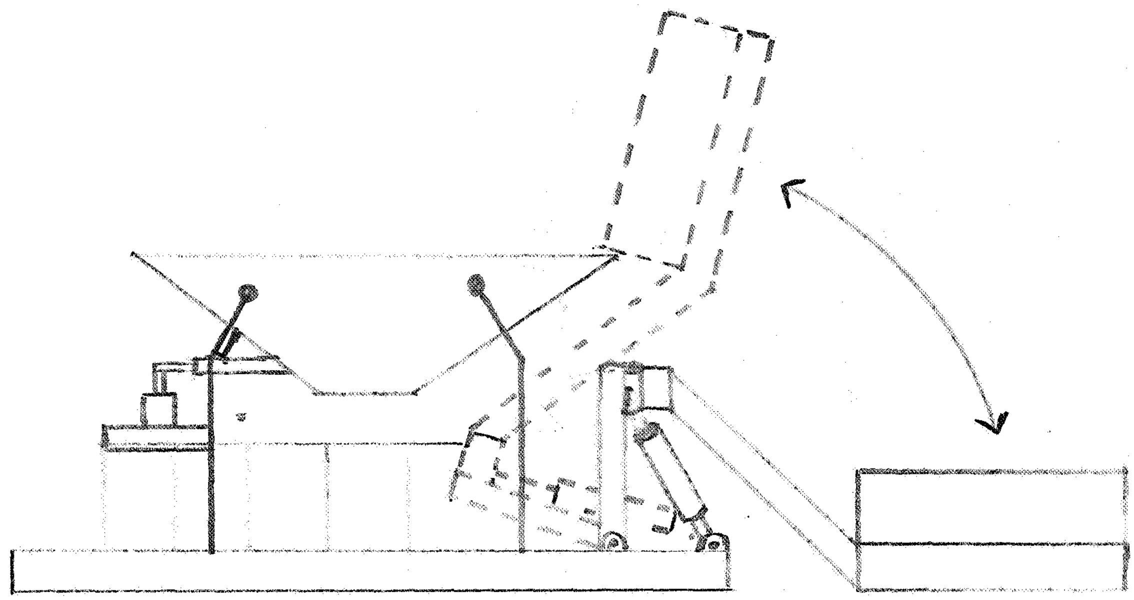
PD-1

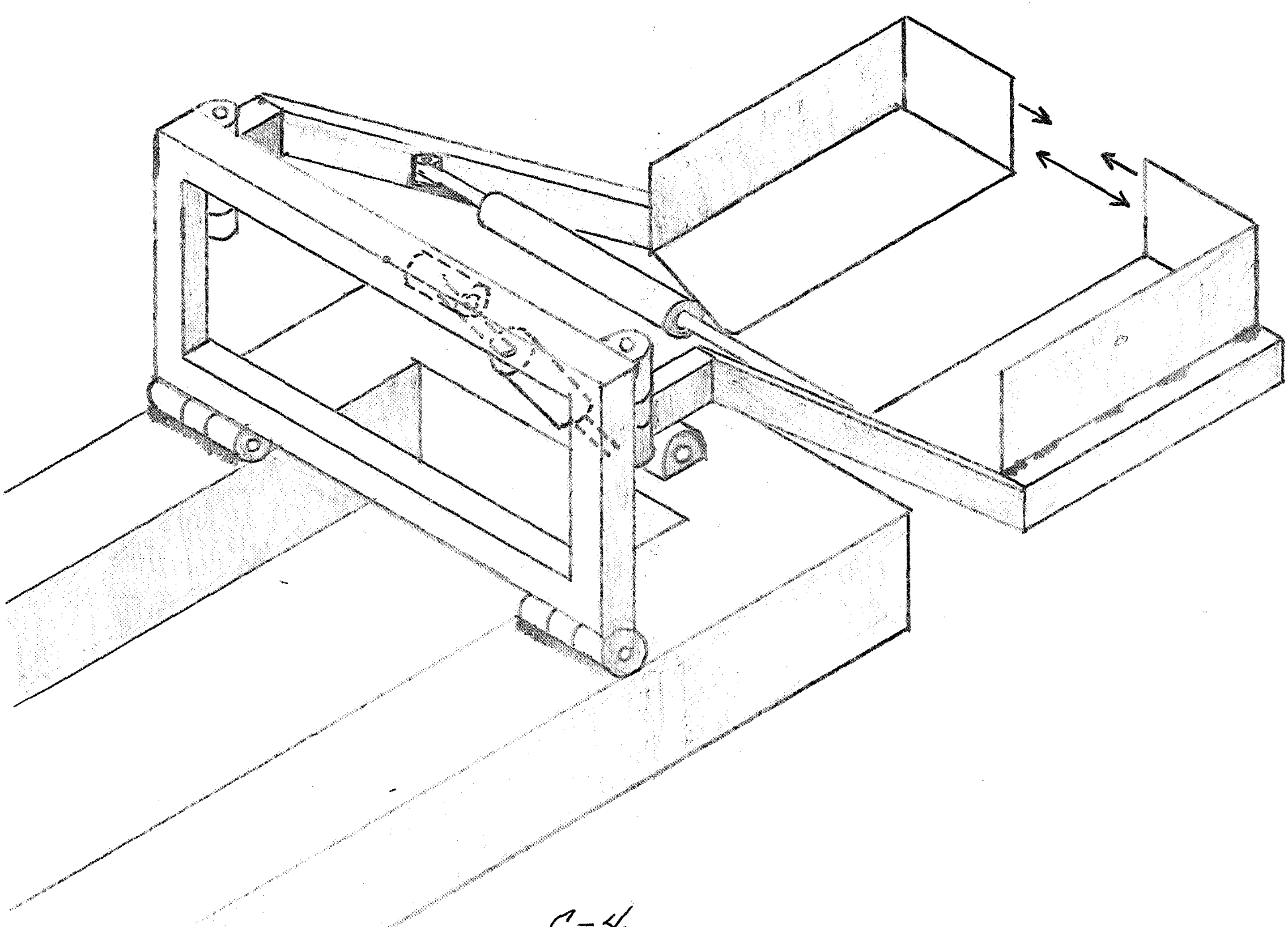


PD-2

GROUP #4
2-4-87
WEEK #4

PD-3





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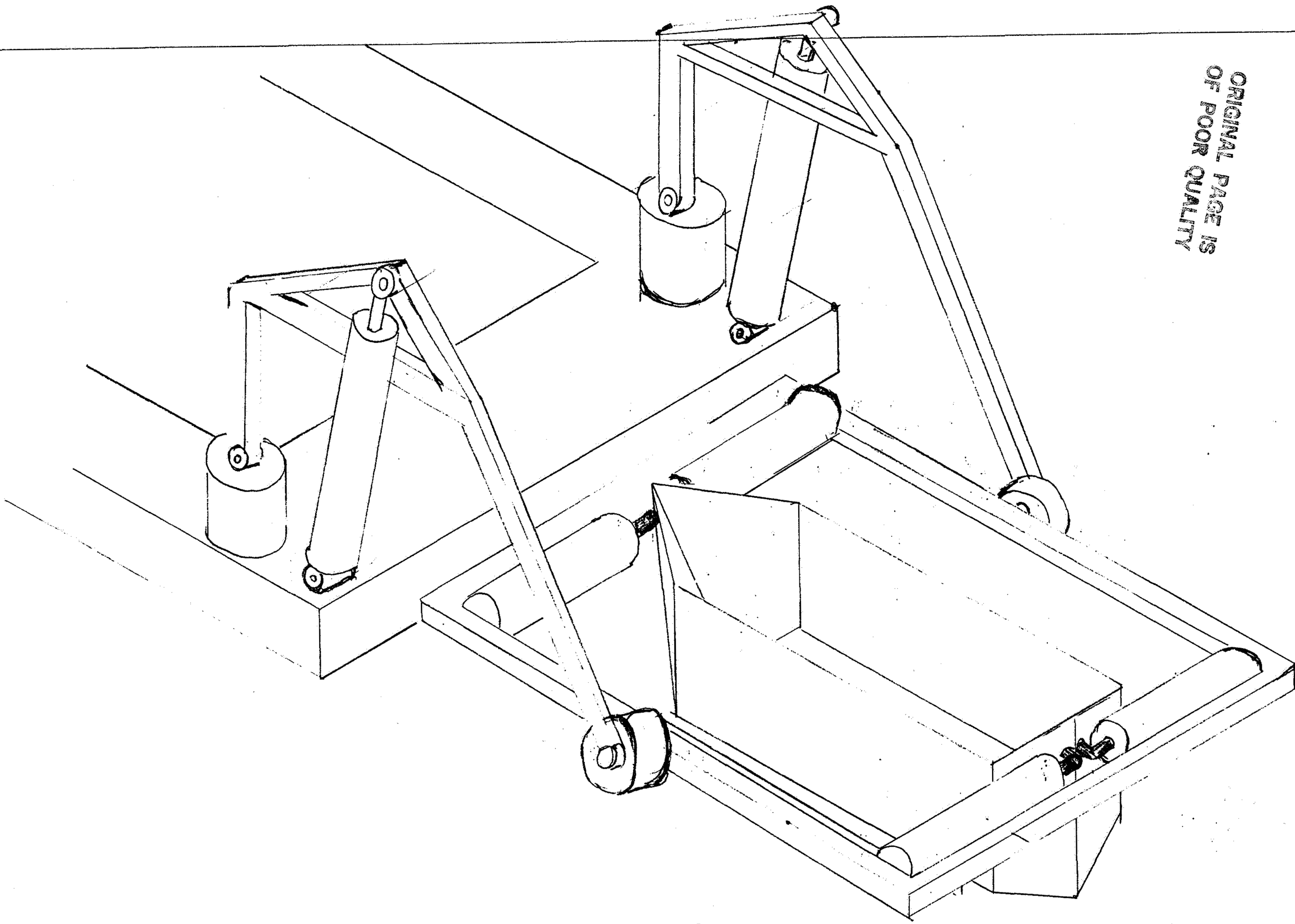
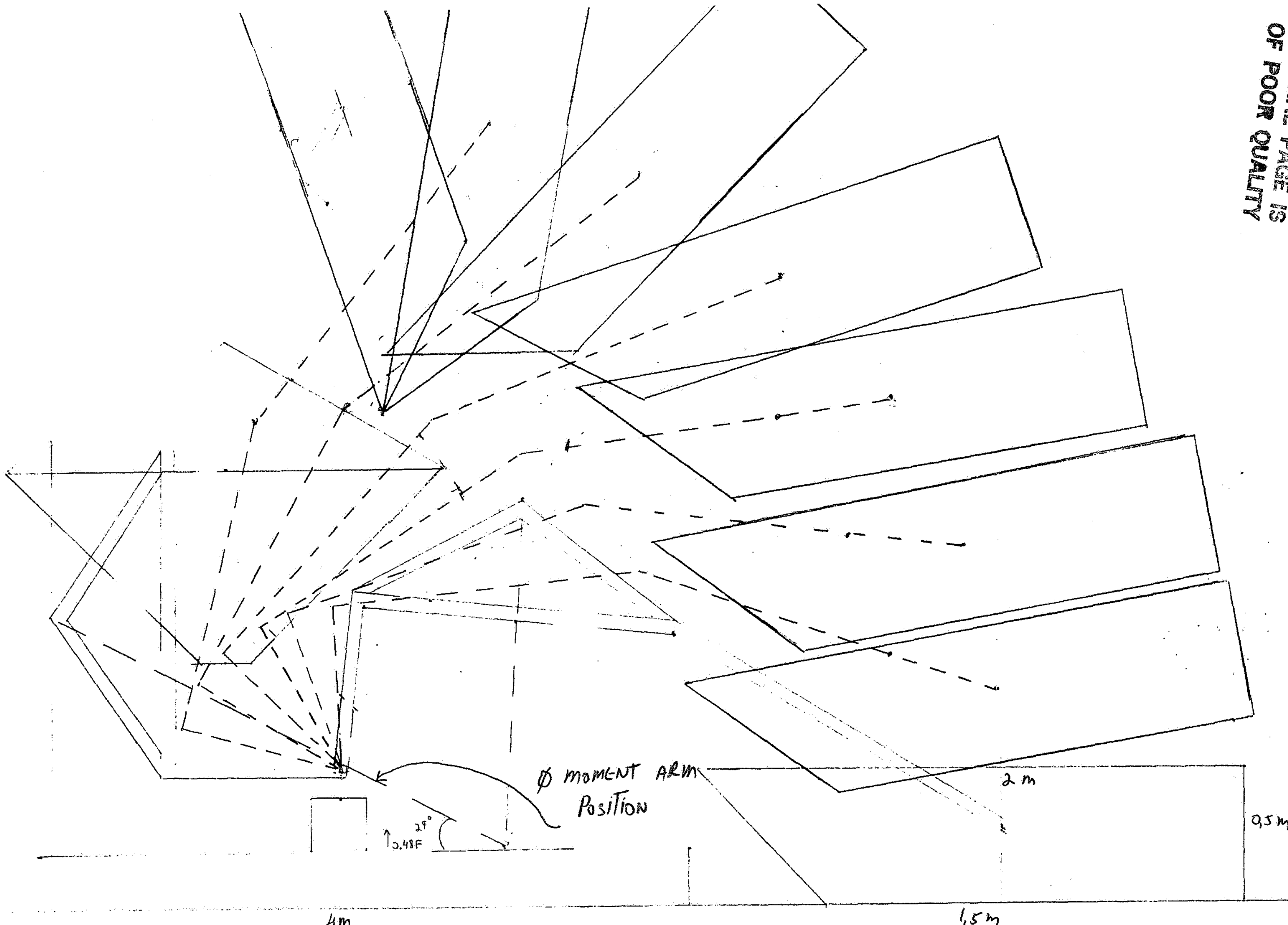


PD-4

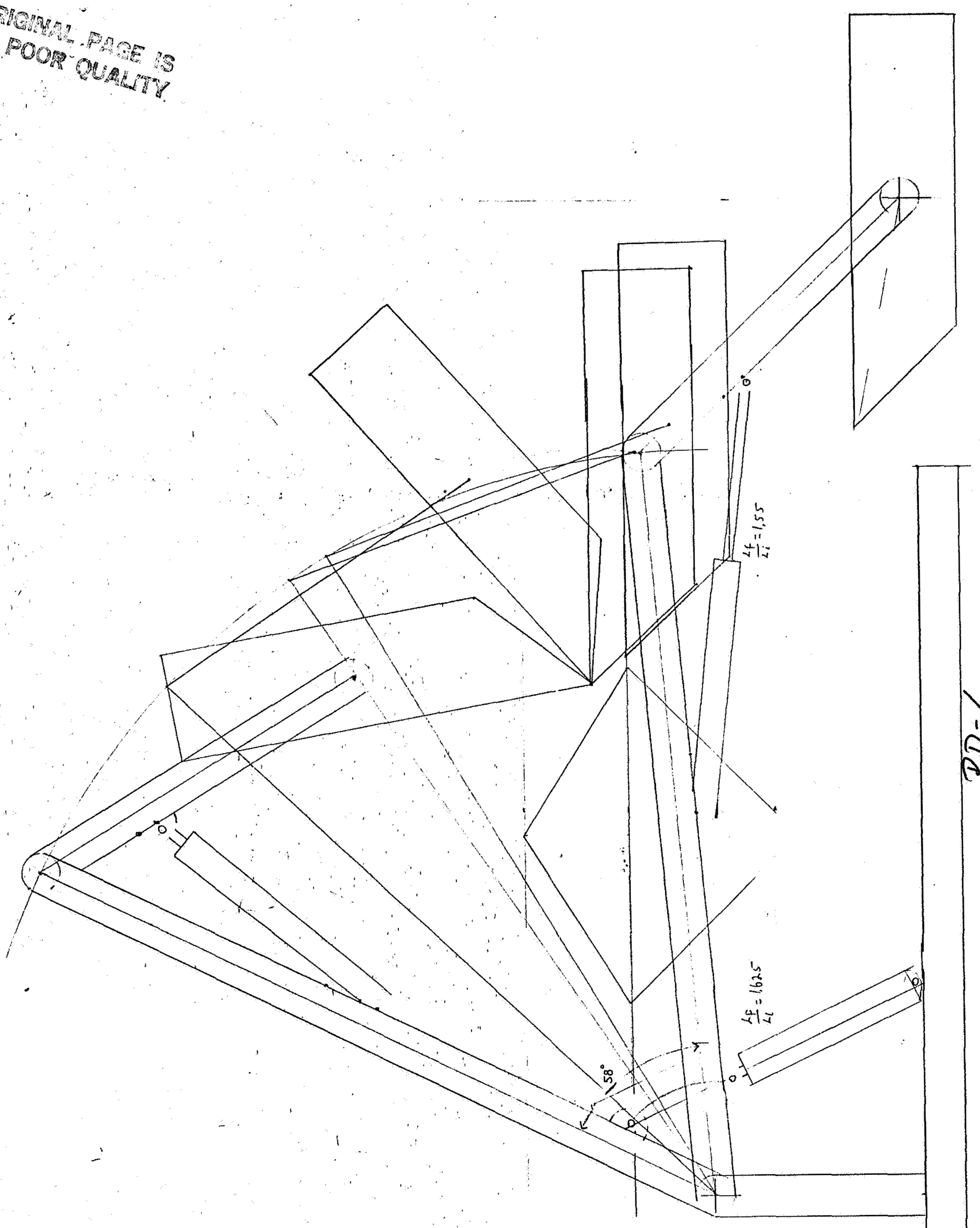
BUCKETS IN A FRAME TO PREVENT BENDING MOMENT ON LIFTING ARMS



PD-5

LIFTING MECH.

REJECTED DUE TO INSUFFICIENT DISTANCE TO LOCATE HYDRAULIC PIVOT IN A WAY WHICH WILL ALLOW OPERATION OVER FULL RANGE


PD-6
58°
Lf/Li = 1.55
Lf/Li = 1.625

(II) **BUCKETS/SCOOPS:**

PD-1: The initial concept for the buckets (refer to page A-xx) involved rectangular scoops being positioned in a "scissor-action".

PD-2: To allow the buckets to "dig-in" to the surface, a 20-degree angled surface with 60-degree beveled edges was added to the bottom of each scoop.

PD-3: The rear portions of the scoops were re-designed using a 45-degree angled slope (refer to page A-xx), to minimize the neccessary pouring angle of the bucket.

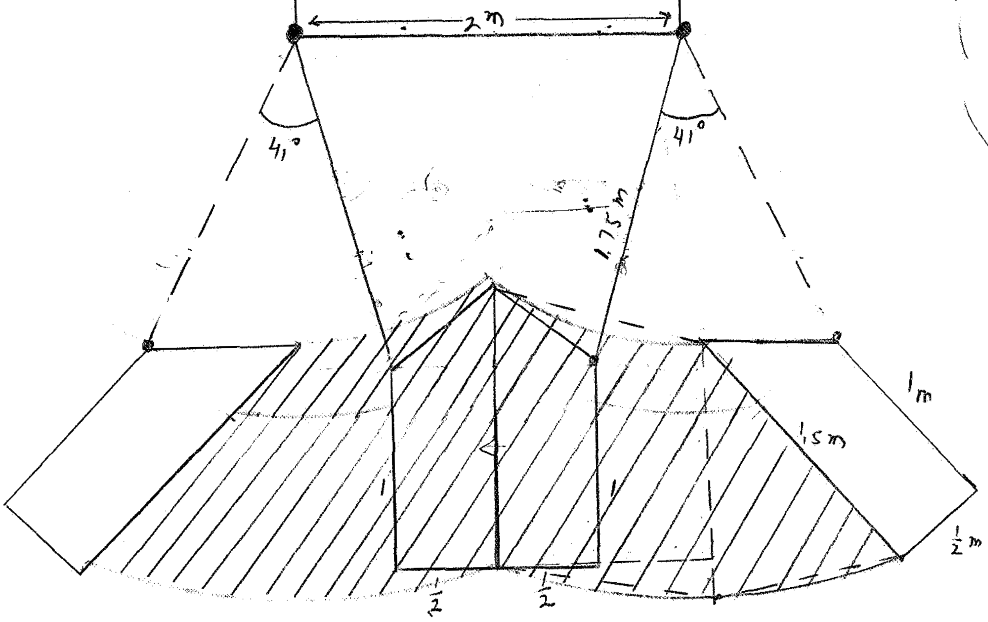
$1 m = 39.37'' = 3.6'$

$1 m^2 = 13 ft^2$

$1.25 m^2 = 16.2 ft^2$

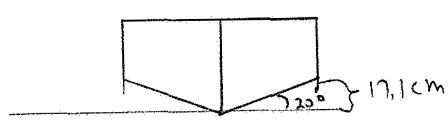
$1 m^3 = 46.7 ft^3$

Scoop vol = $.625 m^3$

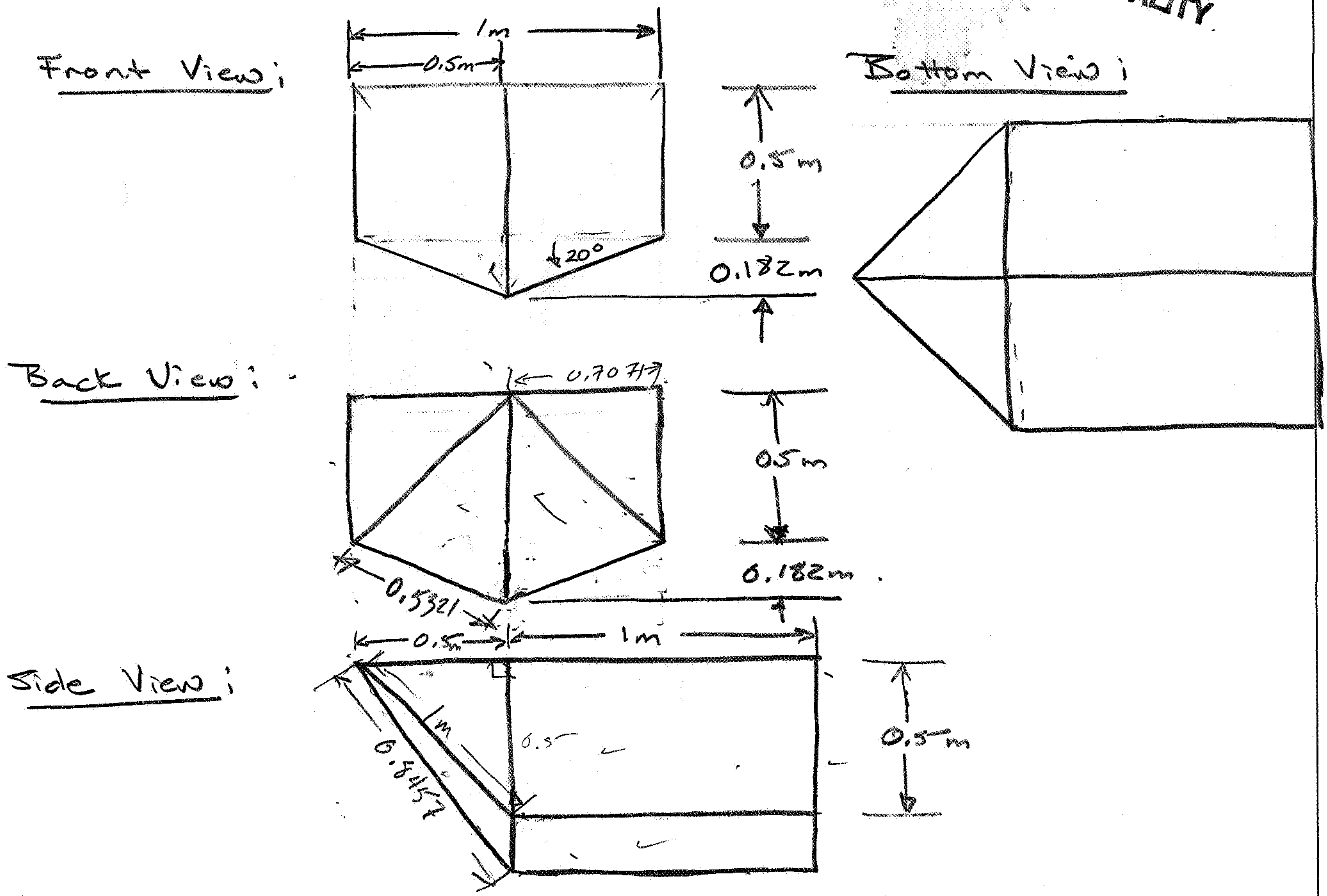


Sweep area $2(1.54 + 1.3) = 5.68 m^2 = 73.84 ft^2$

Based on 2'' soil $\Rightarrow 12.3 ft^3$/sweep. $\cong .27 m^3$



Bucket:



Total Volume = Volume Front Section + Volume Rear Section

$V = 0.5\,m^3 + (0.5)(0.182m)(1m)(1m) = 0.5910\,m^3$

$V_w \approx 0.15\,m^3$

$\boxed{\text{Total Volume (Level fill)} = 0.741\ m^3}$

Total Surface Area $= (2)(0.5321m)(1m) + 3(0.5m)(1m)$
$+ (2)(\frac{1}{2})(.7071m)(0.5m) + 1\,m^2$
$= \underline{3.92\,m^2}$

Assume 8 mm plate thickness

$\therefore$ Total plate volume $= (3.92\,m^2)(0.008\,m) = 0.03136\,m^3$

Aluminum density $= \rho_{AL} = 24.6\ KN/m^3$ (Earth) $\left(\frac{1}{9.8\,\frac{m}{s^2}}\right)\left(\frac{1000\,N}{1\,KN}\right)$

$2.714 \times 10^3\ kg/m^3 \left(\frac{9.8\,m/s^2}{6}\right) = 4.433 \times 10^3\ N/m^3$

$\therefore$ Wt. of bucket (empty) $= 139.03\ N$

APPENDIX D

PRECEDING PAGE BLANK NOT FILMED

APPENDIX D

ADING AND FEEDING MECHANISM DESIGN.

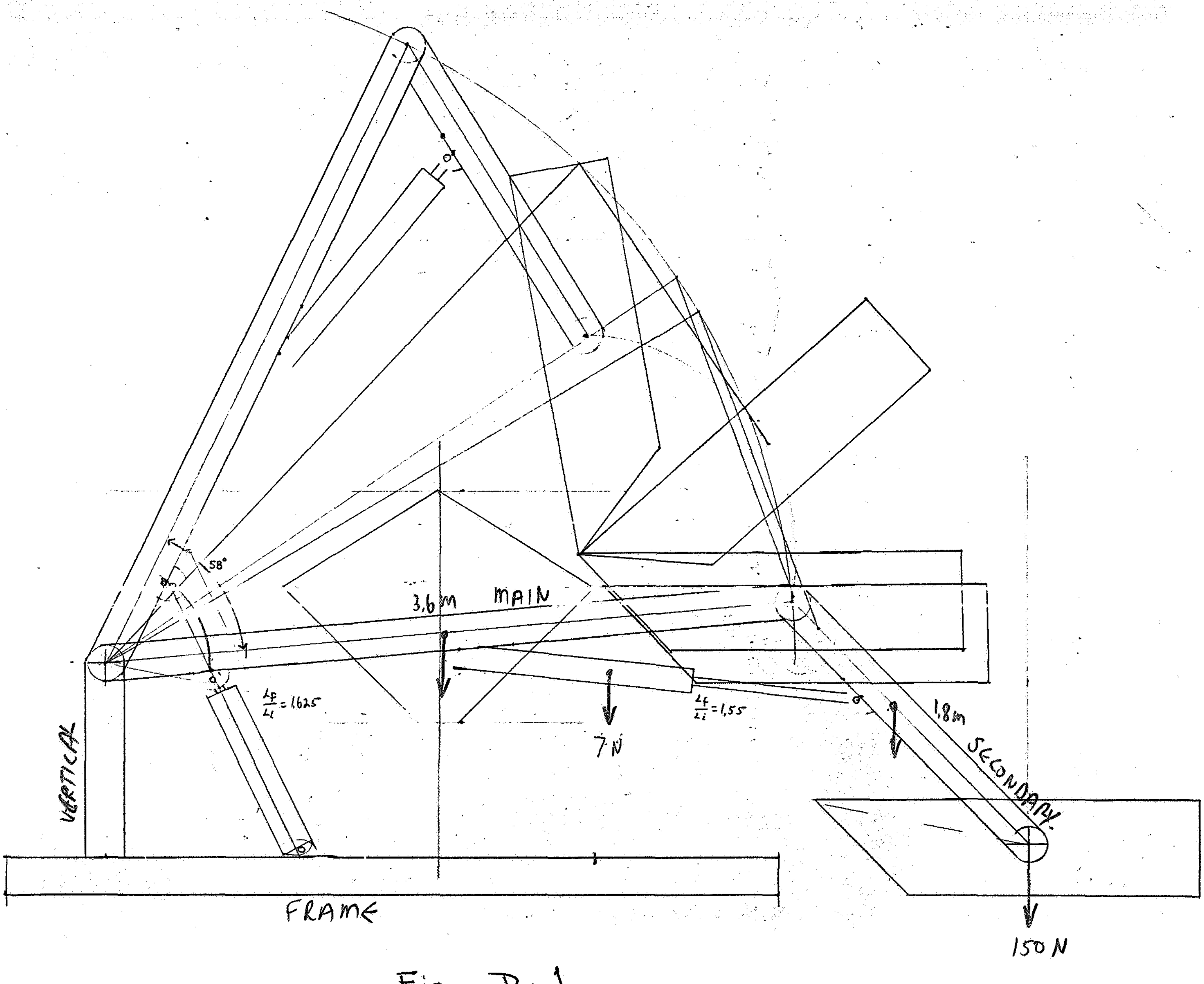


Fig. D.1

3,25 cm = 1 m

$m_{soil} = 1.7 \frac{g}{cm^3}$

$V_{scoop} = 1.1 m^3$

$V_{soil}/_{6''} = 0.45 m^3$

$m_{soil}/_{6''} = 0.45 m^3 \times 1.7 \frac{g}{cm^3} \times \frac{10^6 cm^3}{m^3} \times \frac{kg}{g} \frac{1}{1000} = \boxed{765 N}$

AREA OF AL. FOR SCOOP = $2.7 m^2$

IF WE USE 8 mm SHEET $V_{AL} = 0.0214 m^3 AL \equiv \boxed{57.6 N}$

$\rho_{AL} = 2690 \frac{kg}{m^3}$

4 HYDRAULIC ARMS mass (AL. RODS) $\cong$ 10 kg/UNIT = $\boxed{40 N}$

FRAME WEIGHT $\cong$ 50 N ON MOON

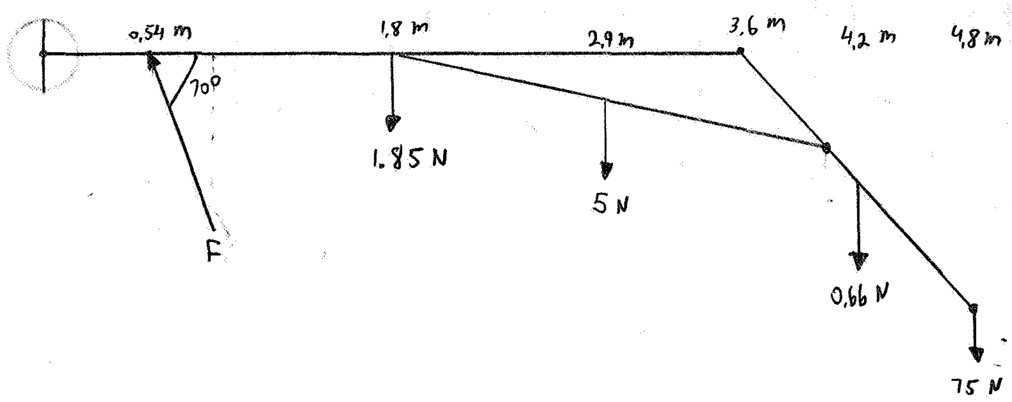
TOTAL WEIGHT OF SCOOP AND SOIL $\cong \frac{915}{6} \cong \boxed{150 N}$ ON MOON.

①

1 m

FORCE REQUIRED AT MAIN CYLINDER TO LIFT SYSTEM

(NEGLECT ACC. EFFECT)



$$\frac{F}{\sin 70} \times 0{,}54\,m = 1{,}85\,N \times 1{,}8\,m + 5\,N \times 2{,}9\,m + 0{,}66\,N \times 4{,}2\,m + 75\,N \times 4{,}8\,m = 380{,}6\,N\text{-}m$$

$$F = \frac{380.6\,N\text{-}m}{0.54\,m} \times 0{,}939 = \boxed{662\ N}$$

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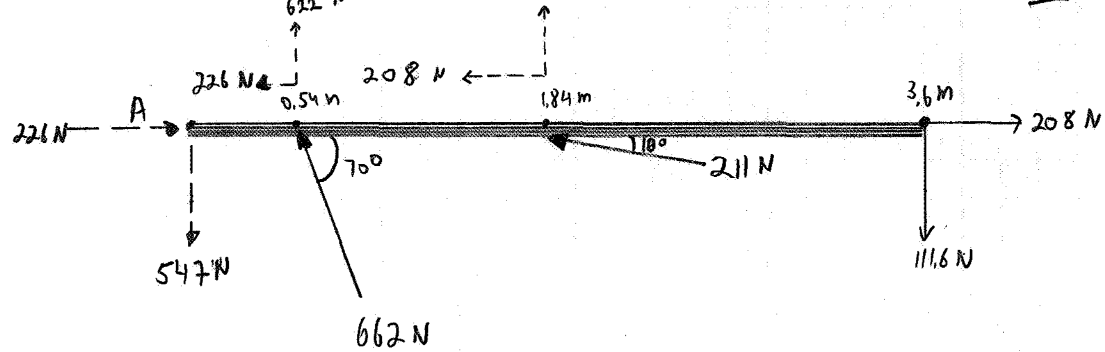
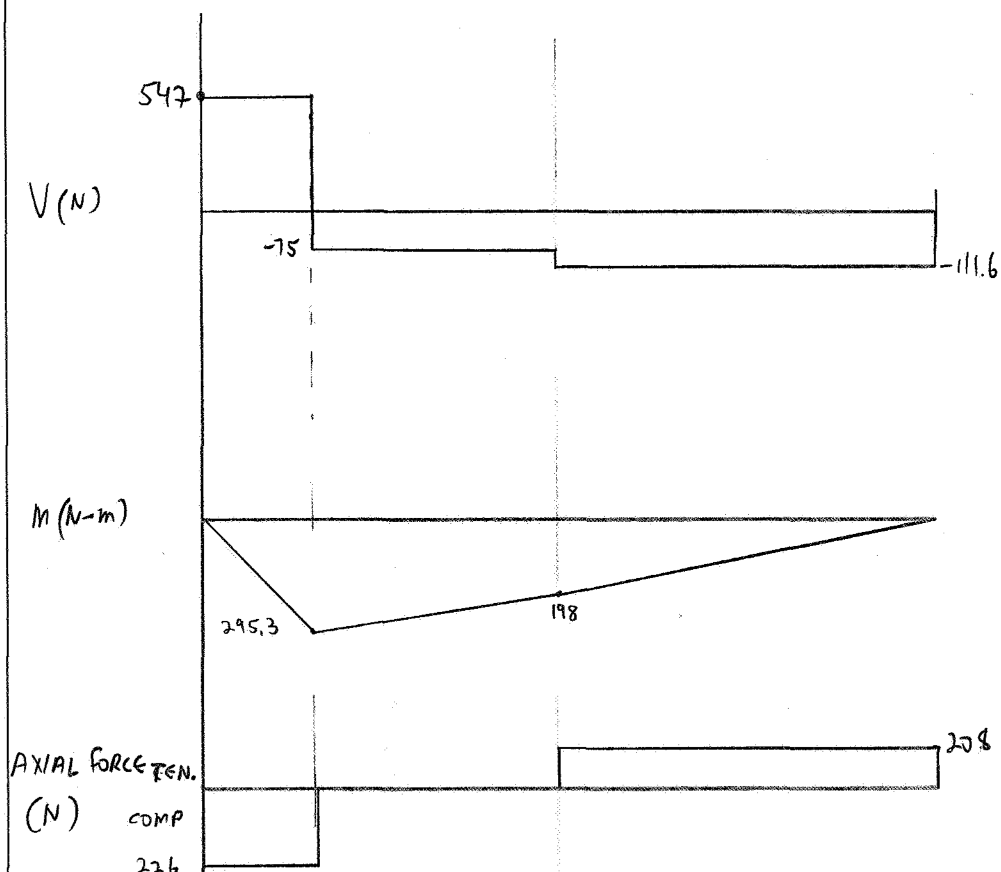
FORCE ANAL. IN MAIN BEAM

FORCES ACTING ON BEAM



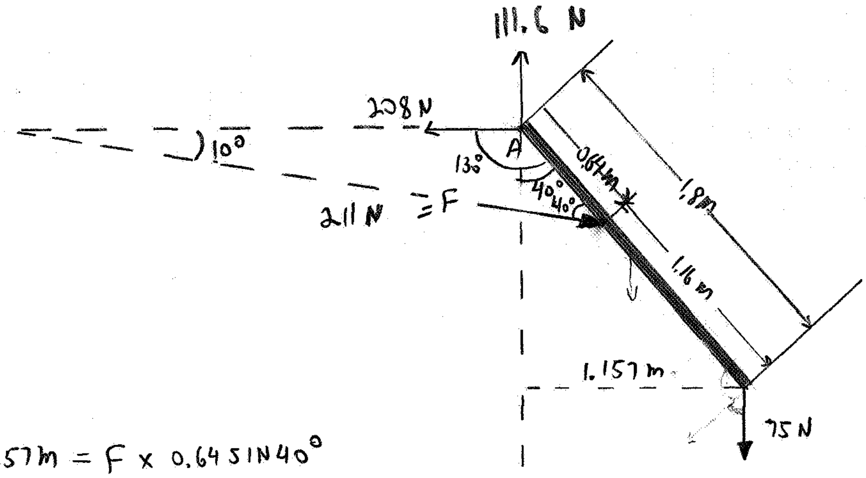
1) CHECK $\Sigma M_A = 0$ OK

2) FIND REACTIONS AT A



FORCE ANAL. OF SECONDARY BEAM

(NEGLECT MASS OF BEAM ≠ 0.66 N)



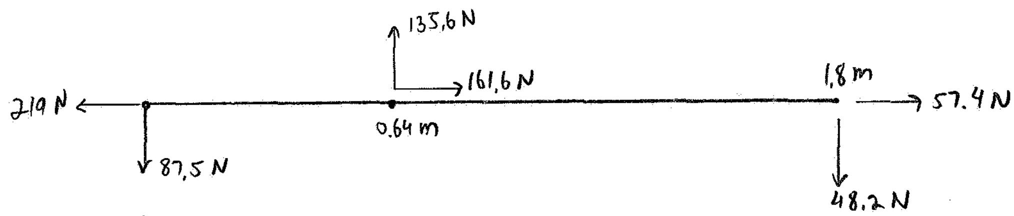
$\Sigma M_A = 0 \Rightarrow$

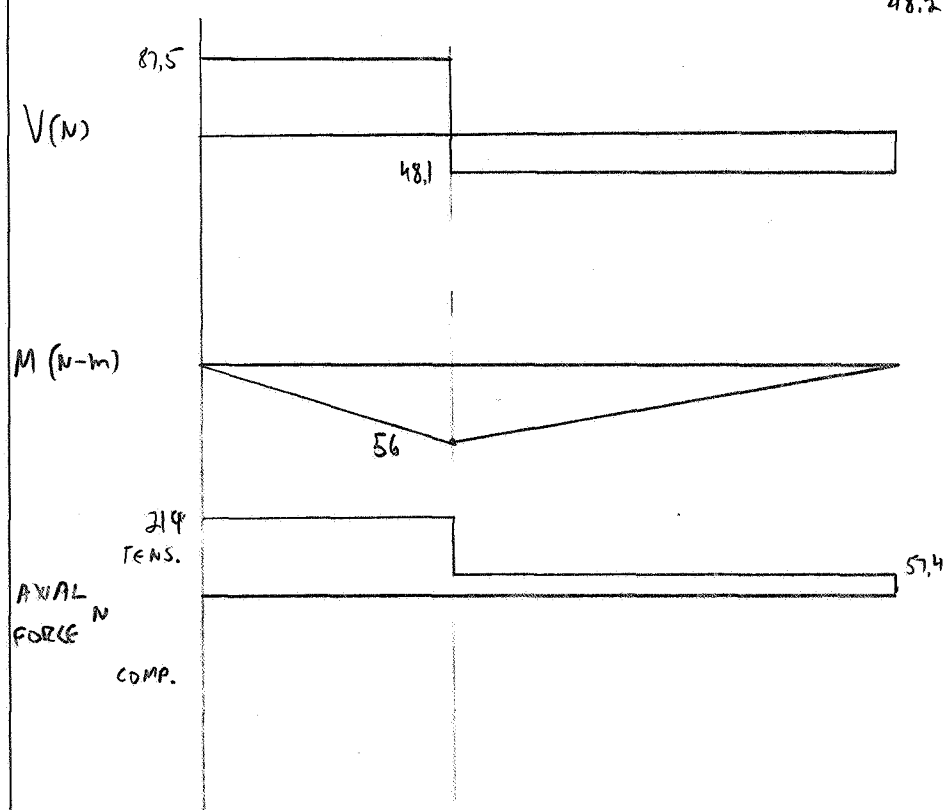
$75\ N \times 1.157\ m = F \times 0.64 \sin 40°$

$\dfrac{86.77\ N\text{-}m}{0.64 \sin 40°\ m} = \boxed{211\ N = F}$

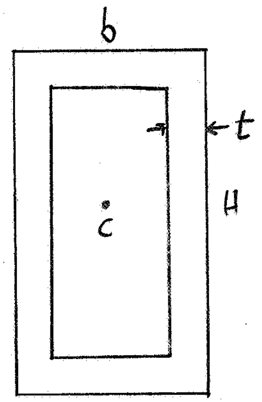
$F \sin 10 \downarrow = 36.63\ N$

$F \cos 10 \rightarrow = 208\ N$





FORCES DUE TO BENDING



$$AREA = HB - (H-2t)(B-2t)$$

$$I = \frac{bH^3}{12} - \frac{(b-2t)(h-2t)^3}{12} \quad (L^4)$$

$$Q = \frac{H^2}{4}t + (b-2t)t\left(\frac{H-t}{2}\right)$$

NORMAL STRESS

$$\sigma_{MAX} = \frac{MC}{I}$$

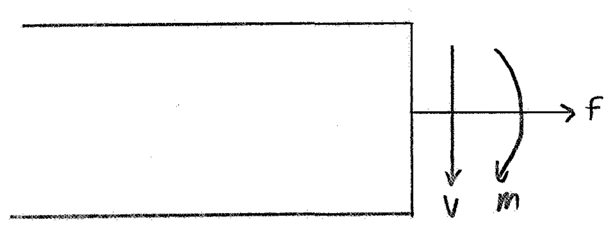
$C = H/2$ for SYMETRIC RECT.

SHEAR STRESS

$$\tau_{MAX} = \frac{QV}{IB}$$

V = max shear force.

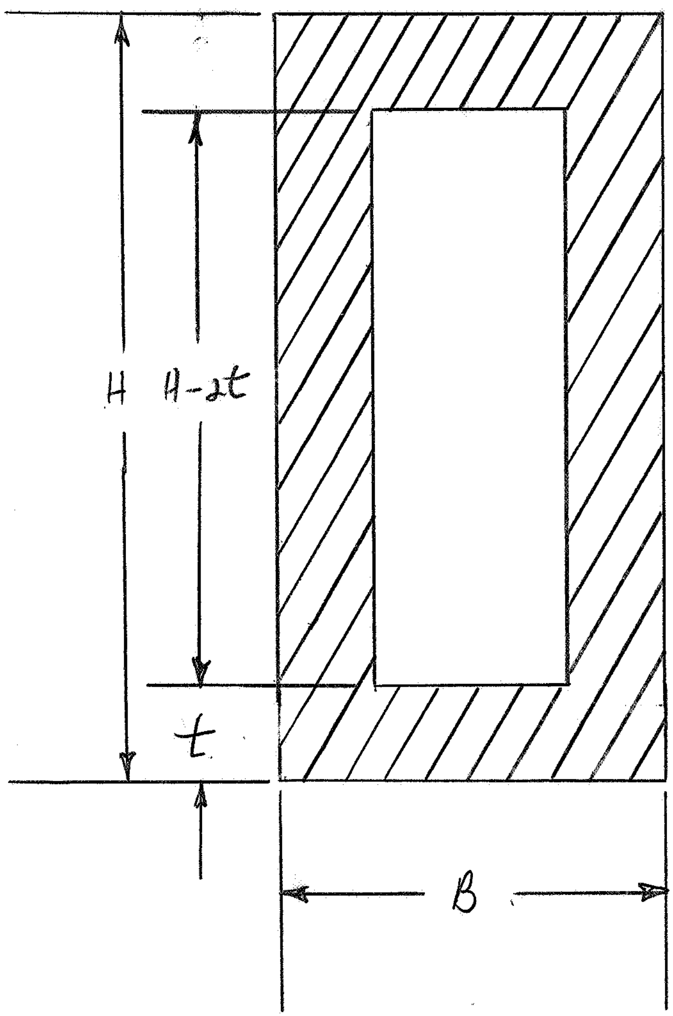
$B = 2t$



ANGLE OF TWIST FOR ROUND BAR

$$\theta = \frac{Tl}{GJ}$$

$$J_{\text{Hollow CIR}} = \frac{\pi}{32}\left(d^4 - d_i^4\right)$$



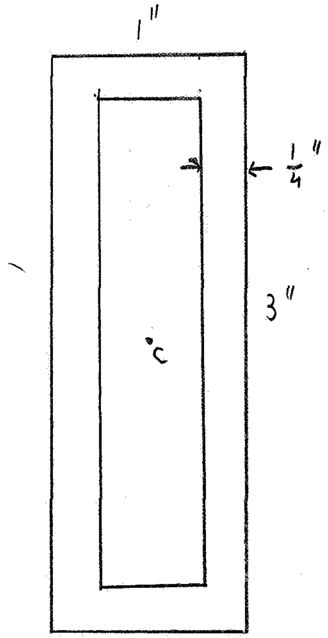
Properties

Series : A97175

Tensile Strength : 80 Ksi
Yield Strength : 70 Ksi
% Elongation : 12.00
Hardness # : 145.00HB
Density : 0.098 lbf/in²

$E = 10.3 \times 10^6$ psi

STRESS ANALYSIS MAIN BEAM



$$Q = \frac{H^2 t}{4} + \left[(b-2t)t\right]\frac{H-t}{2} \quad IN^3$$

$$= \frac{3^2 \times 1/4}{4} + \left[(2.5)\tfrac{1}{4}\right]\frac{2.75}{2} = 1{,}422 \ IN^3$$

$$I = \frac{bH^3}{12} - \frac{(b-2t)(H-2t)^3}{12} =$$

$$= \frac{1 \times 3^3}{12} - \frac{(0{,}5)(2.5)^3}{12} = 1.56 \ IN^4$$

$$V_{MAX} = 547 \ N = 1203.4 \ lb$$

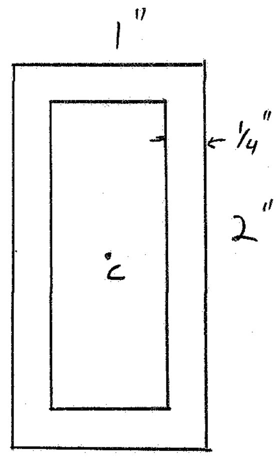
$$\tau_{MAX} = \frac{QV}{2It} = \frac{1{,}422 \ IN^3 \times 1203.4 \ lb}{2 \times 1{,}56 \ IN^4 \times 0{,}25 \ IN} = 2140 \ psi$$

$$\sigma_{max} = \frac{mc}{I} \qquad m = 295{,}3 \ N\cdot m \times 2.2 \ \frac{lb}{N} \times 39.4 \ \frac{IN}{m} = 25{,}596 \ IN\text{-}lb$$

$$\sigma_{max} = \frac{25596 \ IN\text{-}lb \times 1{,}5 \ IN}{1{,}56 \ IN^4} = 24612{,}1 \ psi < 70 \ kpsi$$

$$\frac{\text{WEIGHT ON MOON}}{\text{1 M SECTION}} = 0{,}514 \ kg$$

STRESS ANALYSIS SEC. BEAM



$$V_{MAX} = 87{,}5 \text{ N} = 192{,}5 \text{ lb}$$

$$M = 56 \text{ N-m} = 4854 \text{ IN-lb}$$

$$Q = \frac{(2^2)(\frac{1}{4})}{4} + \frac{1}{2} \times \frac{1}{4} \times \frac{1{,}75}{2} = 0{,}359 \text{ IN}^3$$

$$I = \frac{1 \times 2^3}{12} - \frac{0{,}5 \times 1{,}5^3}{12} = 0{,}526 \text{ IN}^4$$

$$\sigma_{max} = \frac{Mc}{I} = \frac{4854 \text{ IN-lb} \times 1 \text{ IN}}{0{,}526 \text{ IN}^4} = 9227 \text{ PSI}$$

$$\tau_{MAX} = \frac{QV}{2It} = \frac{0.359 \text{ IN}^3 \times 192{,}5 \text{ lb}}{2(0{,}526 \text{ IN}^4)\, 0{,}25 \text{ IN}} = 263.3 \text{ PSI}$$

FOR 1"×1" BEAM

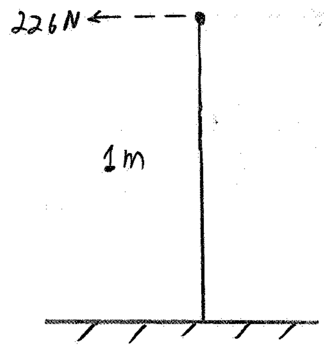
$$I = \frac{1}{12} - \frac{\frac{1}{2} \times \frac{1}{2}^3}{12} = 0{,}0781 \text{ IN}^4$$

$$Q = \frac{1 \times \frac{1}{4}}{4} + \frac{1}{2} \times \frac{1}{4} \times \frac{3}{8} = 0{,}1094 \text{ IN}^3$$

$$\sigma_{MAX} = \frac{Mc}{I} = \frac{4854 \times 0{,}5}{0{,}0781} = 31075 \text{ PSI}$$

$$\tau_{MAX} = \frac{QV}{2It} = \frac{0{,}1094 \times 192{,}5}{2(0{,}0781)0{,}25} = 5392 \text{ PSI}$$

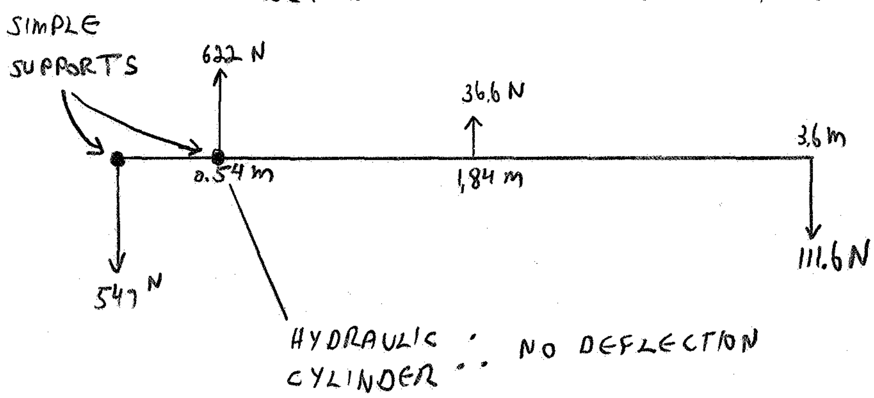
VERTICAL BEAM



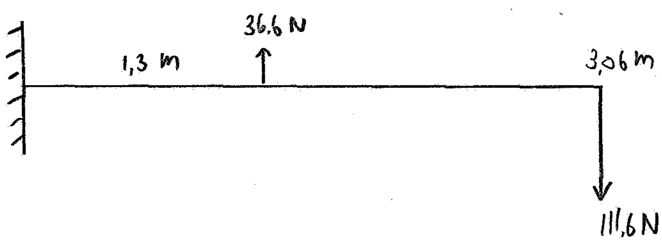
$M_{MAX} = 226 \text{ N-m} = 19575 \text{ IN-lb}$

SAME SIZE AS MAIN BEAM

DEFLECTION ANALYSIS FOR MAIN BEAM



ASSUME NEGLIGIBLE DEFLECTION BETWEEN THE TWO SUPPORT ON LEFT SIDE OF BEAM ⇒ FIXED SUPPORT AT 0.54 m



FOR 36.6 N FORCE

$$Y_{MAX} = \frac{Fa^2}{6EI}(a - 3l) = \frac{80.52 \text{ lb} \times 2621 \text{ IN}^2}{6 \times 10.3 \times 10^6 \text{ PSI} \times 1.56 \text{ IN}^4}\left(51.2'' \;\; 362''\right) =$$

$$= -0.68''$$ SINCE F POSITIVE $0.68''$

FOR 111.6 N FORCE.

$$Y_{MAX} = \frac{Fl^3}{3EI} = \frac{24.6 \text{ lb} \times 1752479 \text{ IN}^3}{3 \times 10.3 \times 10^6 \times 1.56 \text{ IN}^4} = 9''$$ TOO LARGE

INCREASE I BY ABOUT 20 to GET $Y_{MAX} \simeq 0.5''$

FOR $A=5$ $B=2$ $t=0,25$

$$I = \frac{2\times 5^3}{12} - \frac{1,5\times 4,5^3}{12} = 9,44 \text{ IN}^4 \text{ IN}^4$$

$A=8$ $B=4$ $t=0,25$

$$I = \frac{4\times 8^3 - 3,5\times 7,5^3}{12} = 47.6 \text{ IN}^4$$

$A=8$ $B=3$ $t=0,25$

$A=5.25 \text{ IN}^2$ $\boxed{I = \frac{3\times 8^3 - 2,5\times 7,5^3}{12}} = 40.1 \text{ IN}^4 \Rightarrow Y_{MAX} = 0.55''$ 10% MORE MASS THEN

$\boxed{A=7 \quad B=3 \quad t=0,25}$

$A=4,75$ $I = \frac{3\times 7^3 - 2,5\times 6,5^3}{12} = 28,5 \text{ IN}^4 \Rightarrow Y_{max} = 0.77''$

$A=4$ $B=2$ $t=0,5$

$$I = \frac{2\times 4^3 - 1\times 3^3}{12}$$

$A=6$ $B=2$ $t=0,5$

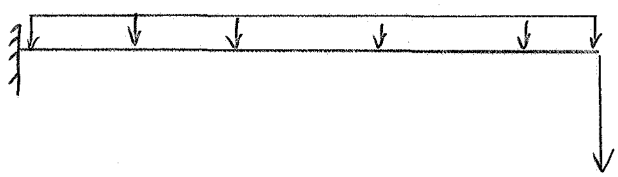
$A=7$ $I = \frac{2\times 6^3 - 1\times 5^3}{12} = 25,58$

USING $8'' \times 3'' \times 0{,}25''$ THICK MEMBER ⇒ 1m OF MEMBER WEIGHS 9.11 kg

FOR SECONDARY BEAM

45.7''

w= 0,2 lb IN



128 lb ⇒

$$Y_{max} = \frac{-Fl^3}{3EI} = \frac{128\,lb \times 46^3\,IN^3}{3 \times 10{,}3 \times 10^6\,PSI \times 0{,}526\,IN^4} = 0{,}766\ IN$$

TRY $3'' \times 1'' \times 0{,}25''$ THICK

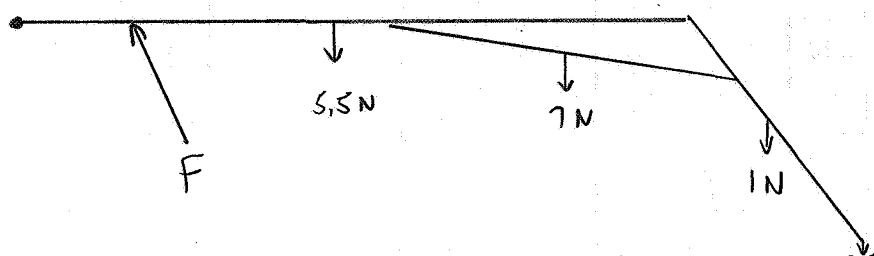
$$I = \frac{1 \times 3^3 - 0{,}5 \times 2{,}5^3}{12} = 1.6\ IN^4 \Rightarrow Y_{max} = 0{,}25\ IN$$

FINAL DIMENTIONS

DUE TO DEFLECTION CONCIDERETION

		EARTH	MOON
MAIN BEAM =	$8''_H \times 3''_W$ $\frac{1}{4}''$ THICK (20.3 cm, 7.6 cm)	9.1 kg/m SECTION	1.52 kg/m
SECONDARY BEAM =	$3''_H \times 1''_W$ $\frac{1}{4}''$ THICK.	3.12 kg/m SECTION	0,52 kg/m

NEW FORCE IN MAIN CYLINDER (AFTER FINAL CROSS SECTION WAS SELECTED)

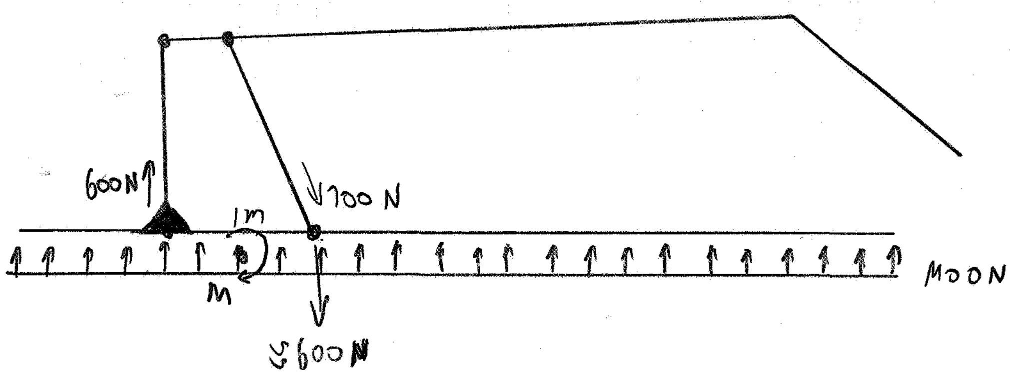


$$\frac{F}{\sin 70} \times 0{,}54\,m = 5{,}5 \times 1{,}8 + 7 \times 2{,}9 + 1 \times 4{,}2 + 75 \times 4{,}8 =$$

$$= \underset{\text{NEW}}{394} \cong \underset{\text{OLD}}{380}$$

$F \cong 700$ N

PLATFORM BEAMS



M DUE TO A COUPLE = F·r = 600 N·m = 52000 IN-lb

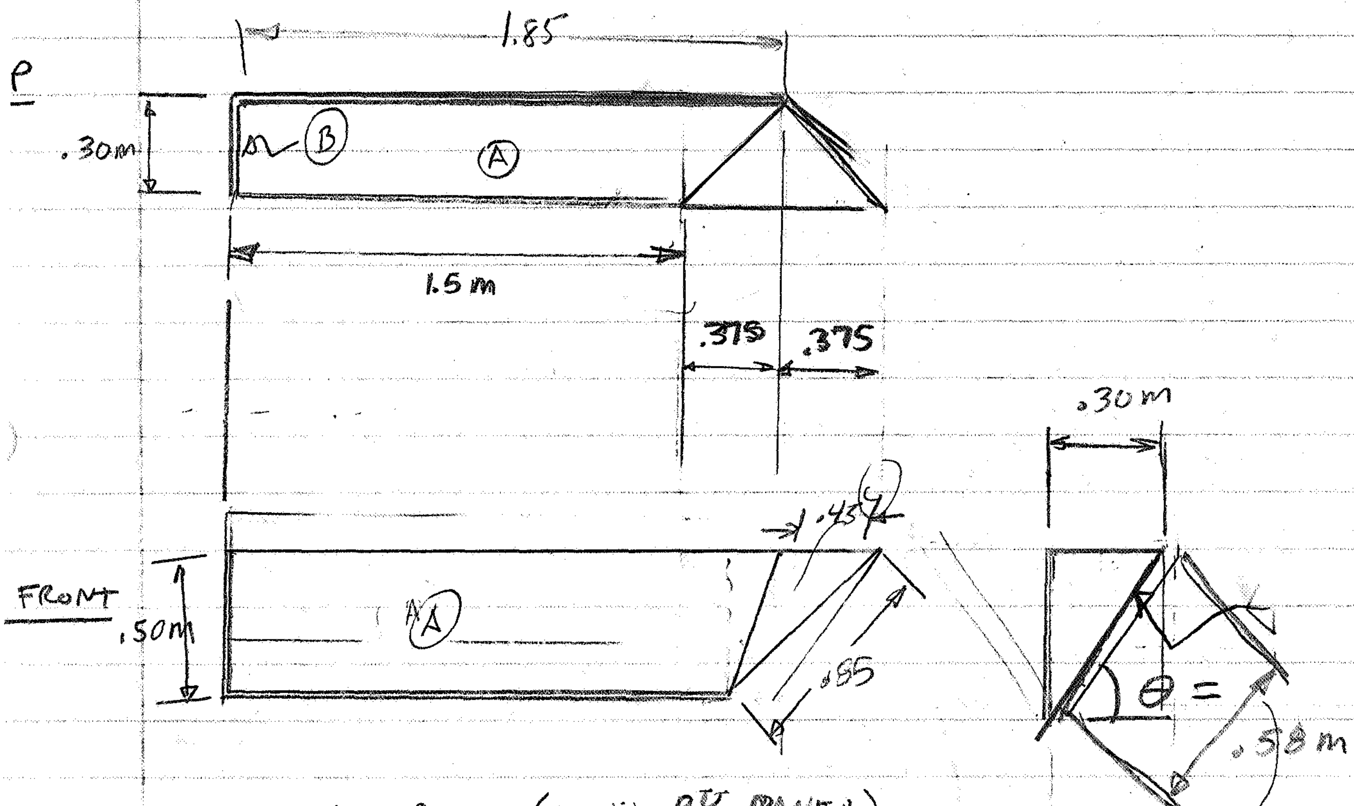
USE 8" H X 6" W X $\frac{1}{4}$" T BEAM

3 SCOOP – DIMENSIONS & CONSTRUCTION

MATERIAL – ALUMINUM : A97175 $S_{ut} = 80\ kpsi = 5.51 \times 10^{8}\ Pa$

$S_{sy} = 70\ kpsi$

SKEMATIC DRAWING:



SURFACE AREA (PANEL BY PANEL)

Ⓐ $(1.50m \times .58m) + \left(\frac{.35 \times .58}{2}\right) = .97 m^2$

Ⓑ $\left(\frac{.50 \times .30}{2}\right) = .075\ m^2$

Ⓒ $\left(\frac{.85 \times .45}{2}\right) = .1913$

{ CHANGE THIS TO OBTAIN A SCOOP VOLUME OF AT LEAST .228 m^3 }

1 SCOOP HAS SURFACE AREA OF : $A = 1.236\ m^2$

2 SCOOPS HAVE $A = 2.473 \simeq \boxed{2.5\ m^2}$

(OVER)

TO CALCULATE THE MASS OF THE SCOOP, MULTIPLY :

$\cancel{t = 1.0\,cm}$ $\qquad V = t * A = (.01m) * 2.5m^2 = .025m^3$

$$m = \rho V = \left(2.67\frac{g}{cm^3}\right) * \frac{1KG}{1000g} * \left(\frac{100\,cm}{1m}\right)^3 (.025\,m^3)$$

$$\boxed{m = 66.75\ KG}$$

(SI) $\quad$ WEIGHT$|_{earth} \cong 655.5$ NEWTONS

(BRITISH) $\quad$ WEIGHT$|_{earth} \cong 147.5$ lbs

---

t = .5 cm $\quad$ IF SHEET ALUMINUM OF HALF THE THICKNESS IS USED, THEN

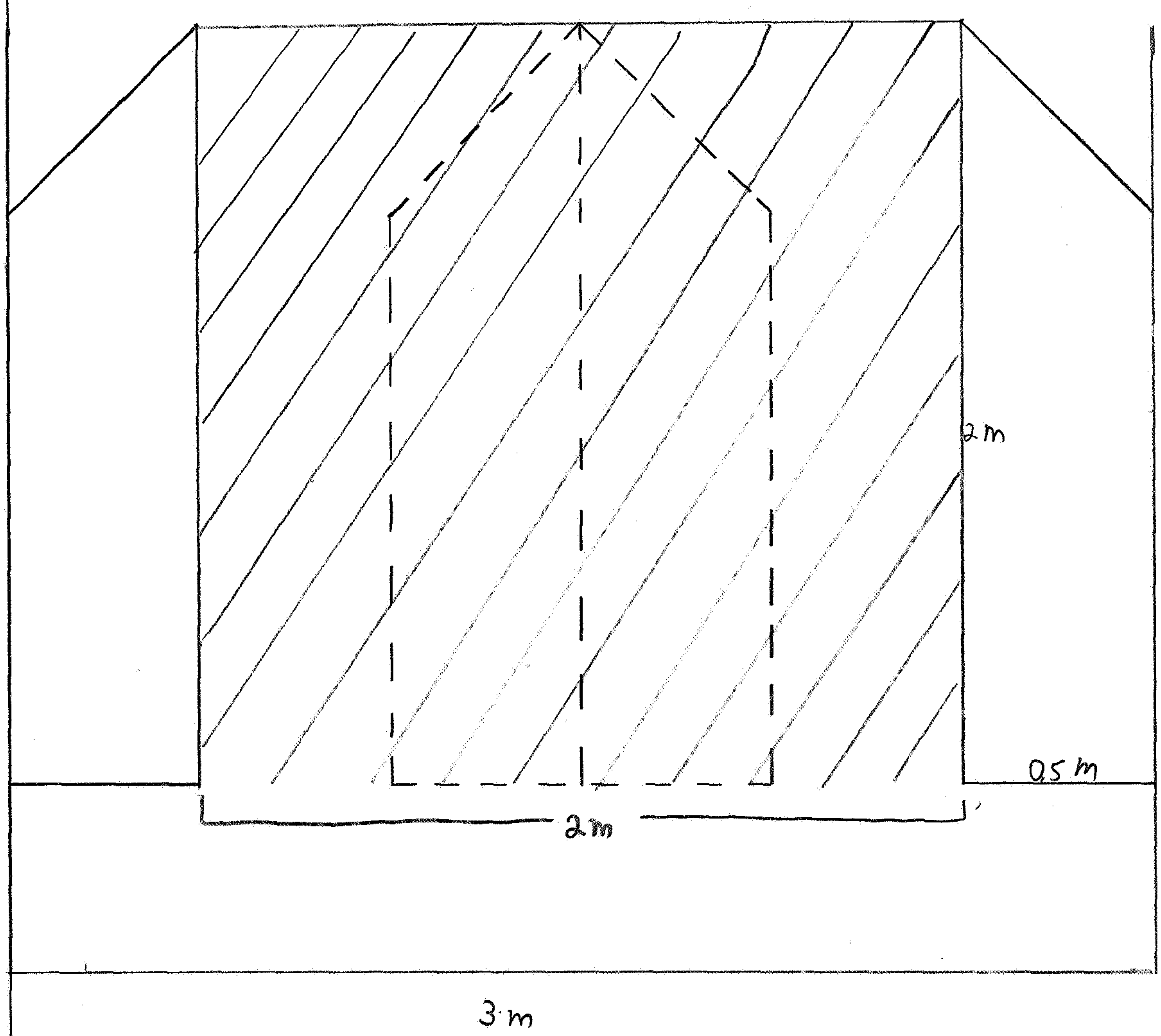
use this

$$\boxed{m = 33.375\ kg}$$

$$W|_{EARTH} = 73.74\ lbs = 327.74\ NEWTONS$$

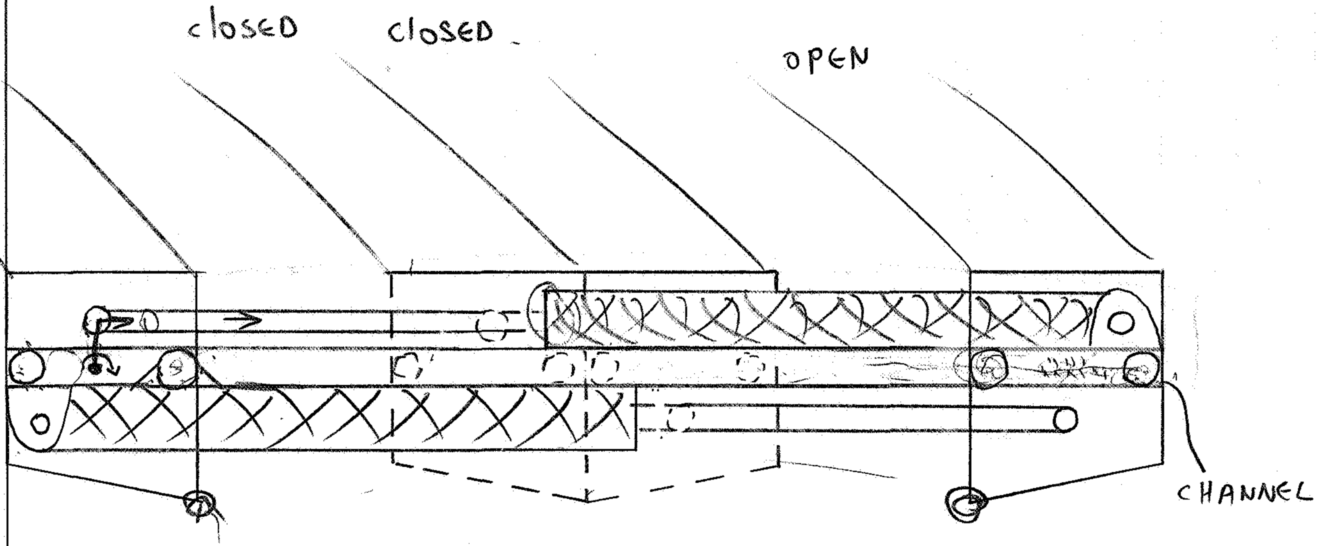
D.16 A

TOP VIEW OF SCOOPS

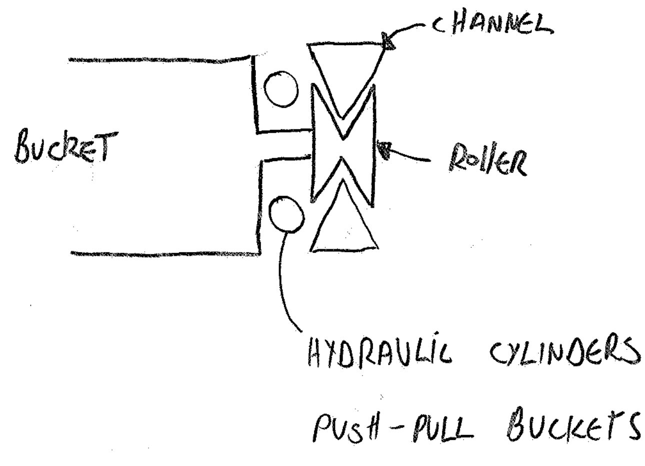


SHADED AREA = $2\,m^2$ = AREA to be SCOOPED EACH time

OPEN close motion of BUCKETS



FROM EACH BUCKET TWO Rollers Will Roll ON CHANNEL TO CARRY MOMENT

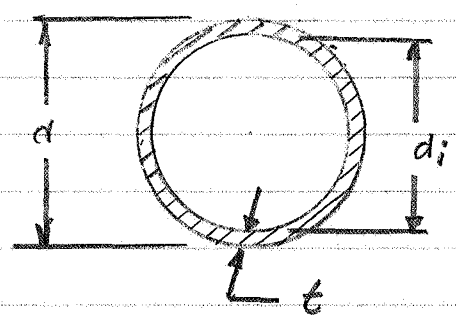


(3) (4) SCOOP SUPPORT BRACKETS

THE SCOOP SUPPORT BRACKETS SERVE TWO PURPOSES FOR THE SCOOPING MECHANISM:

1) ACTS AS A STIFFENING MEMBER FOR THE SHEET ALUMINUM SCOOPS.
2.) PROVIDE A MEANS OF ATTACHING THE SCOOP TO THE HYDRAULIC FORCE CYLINDERS, AND THE ROLLERS TO GUIDE THE MOTION OF THE SCOOPS.

- THE BRACKETS WILL BE CONSTRUCTED OF 3 cm O.D. HOLLOW TUBING, WITH 2 mm WALL THICKNESS



$$A = \frac{\pi}{4}(d^2 - d_i^2)$$

$$I = \frac{\pi}{64}(d^4 - d_i^4)$$

$$\bar{y} = \frac{d}{2}$$

ALUMIN. $$\text{mass} = \rho A \cdot l = \rho\left[\frac{\pi}{4}(d^2 - d_i^2)\right] l$$

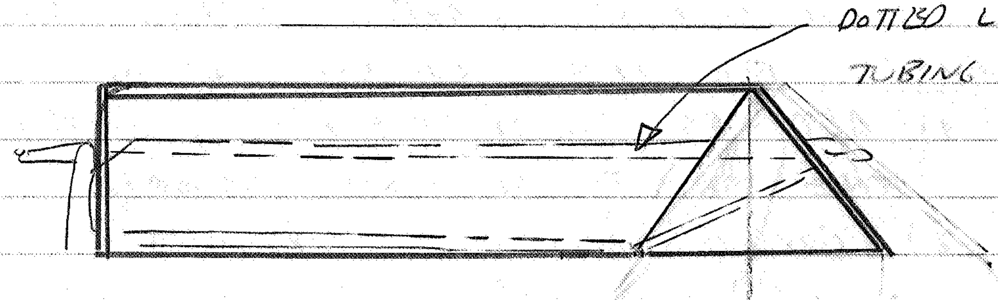
$$A = \frac{\pi}{4}(.03^2 - .026^2) = 1.759 \times 10^{-4}\ m^2$$

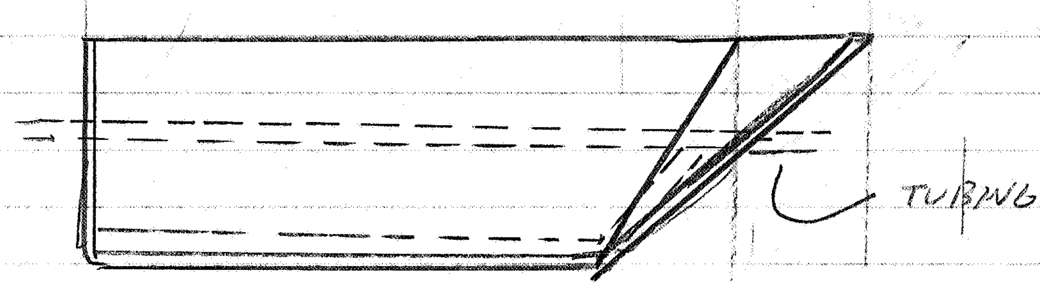
$$\rho = 2.699\ g/cm^3 * \frac{(100\ cm)^3}{1\ m^3} * \frac{1\ KG}{1000\ g} = \underline{2699\ KG/m^3}$$

$$\boxed{\text{mass}/\text{meter} = 4.468\ KG/\text{meter}}$$

(OVER)

BRACKET MOUNTING ON SCOOP





ESTIMATED WEIGHT OF TUBING USED FOR EACH SCOOP.

2 m
1.5 m
.175 m
.175 m
.250 m

TOTAL TUBING FOR 1 SCOOP → 4.1 m/scoop

TOTAL TUBE USED = 8.2 meters.

$M = (4.468\ \mathrm{KG/m})(8.2\ \mathrm{m}) = 36.638\ \mathrm{KG}$

$W_{EARTH} = 359.78$ NEWTONS $= 80.95$ lbs

ORIGINAL PAGE IS OF POOR QUALITY

(4) B. HYDRAULIC FORCE CYLINDERS FOR SCOOPING MOTION.

FORCE REQUIRED TO SCOOP SOIL: 465 lbs

$F = 2060\,N$ (SI)
$F \cong 465\ lbs$ (BRIT)

★ SYSTEM OPERATING PRESSURE = 750 psi

$$A = \frac{F}{P} = \frac{465\ lbs}{750\ lbs/in^2} = .62\ in^2$$

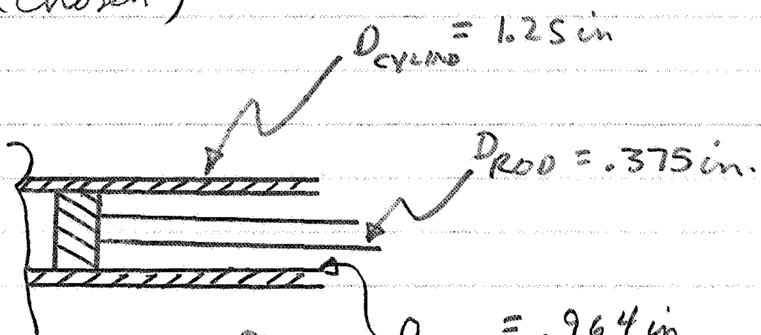
$$F = \text{PULL FORCE}\Big|_{\text{PISTON}} = (\text{BORE AREA} - \text{ROD AREA}) \times \text{PRESSURE}$$

$$\text{AREA} = .62\,in^2 = (\text{BORE AREA} - \text{ROD AREA})$$

$$.62\,in^2 = \frac{\pi}{4}(d_o^2 - d_i^2)$$

$$\left(\frac{4A}{\pi} + d_i^2\right)^{1/2} = d_o = \text{BORE DIAMETER.}$$

d_o	d_i	d_c
.916	.25	
.964	.375	1.25 in (chosen)



2. TRACK / RAIL ANTIFRICTION ASSEMBLY

THIS PORTION OF THE DESIGN RESULTED FROM THREE BASIC NEEDS:

1 - A LINK WAS NEEDED TO DEFINE THE PATH OF THE SOIL SCOOPING MOTION (LINEAR).
2 - A LINK WAS NEEDED TO PROVIDE STRUCTURAL SUPPORT FOR THE SCOOPS & PROTECTION FOR THE HYDRAULIC CYLINDERS (AGAINST THE ELEMENTS).
3 - A MECHANISM OR JOINT SYSTEM WAS NEEDED TO REDUCE FRICTION & WEAR OF THE SCOOPING MECHANISM.

REFERRING TO DRAWING #_____ ONE CAN SEE THAT THE WHEELS OF THE ANTI-FRICTION MECHANISM ARE BEVEL, OR DOVETAIL CUT SO THAT THE WHEEL/RAIL INTERACTION PROVIDES A REACTION IN THE DIRECTION ALONG THE WHEEL'S AXIS AS WELL AS NORMAL TO THE CONTACT POINTS. IF FAIRLY LOOSE TOLERANCES ARE USED, THE SHARPNESS OF THE MATING LINKS SHOULD HELP REDUCE DEBRIS ENTRAPMENT.

BY PLACING THE HYD. CYLINDERS WITHIN THE HOUSING, THEIR SHAFTS ARE PROTECTED FROM IMPACTING OBJECTS, PLUS, THEY WON'T BE EXPOSED TO AS MUCH FLOATING DUST.

(OVER)

RECOMMENDATIONS:

- THE WHEELS AND RAILS SHOULD BE MADE OF THE HARDEST MATERIALS POSSIBLE TO ~~AVOID~~ REDUCE EXCESSIVE WEAR.
- MORE IN-DEPTH STRESS ANALYSIS SHOULD BE PERFORMED, SO THAT SMALLER MEMBERS WEIGHING LESS MAY BE USED.

WEIGHT CALCULATIONS:

SEE DWG # ____

① $D_{AVG} = \frac{D_o + D_i}{2} = \frac{2.15\,in + 1.2\,in}{2} = 1.675\,in$

$\forall \big|_{WHEEL} = \frac{\pi D_{AVG}^2}{4} \cdot l = \frac{\pi}{4}(1.675)^2(.8) = 1.763\,in^3$

$= 28.9\,cm^3$

$(W_{EARTH} = .765\,N = .172\,lbs) \times 8$

$W \cong 1.4\,lbs$

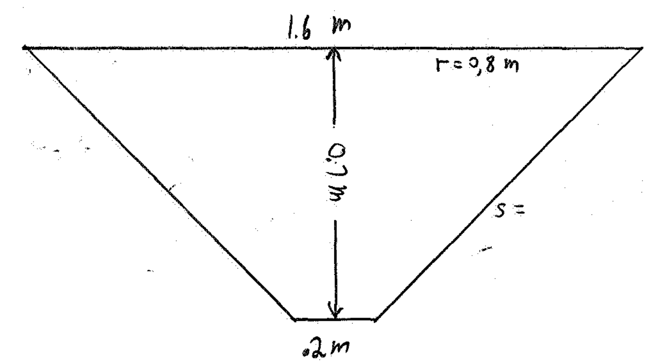
② $A\big|_{2/x\text{-}sect} = .0006785\,m^2$ @ $V_2 = A \cdot l = .00203\,m^3$

$m = \rho \forall$

⋮

(Weights given on Prints)

HOPPER



AREA OF CONE $= \pi r s = \pi\, 0{,}8 \times 1{,}3 - \pi\, 0{,}1 \times 0{,}4 = 2.8\ m^2$

$t_{wall} = 5\ mm$

$V_{metal} = 2.8\ m^2 \times 0.005 = 0{,}014\ m^3$

$W_{HOPPER} = 0{,}014\ m^3 \times 2690 \frac{kg}{m^3} = 37.66\ kg_{earth} \approx 6.3\ kg_{moon}$

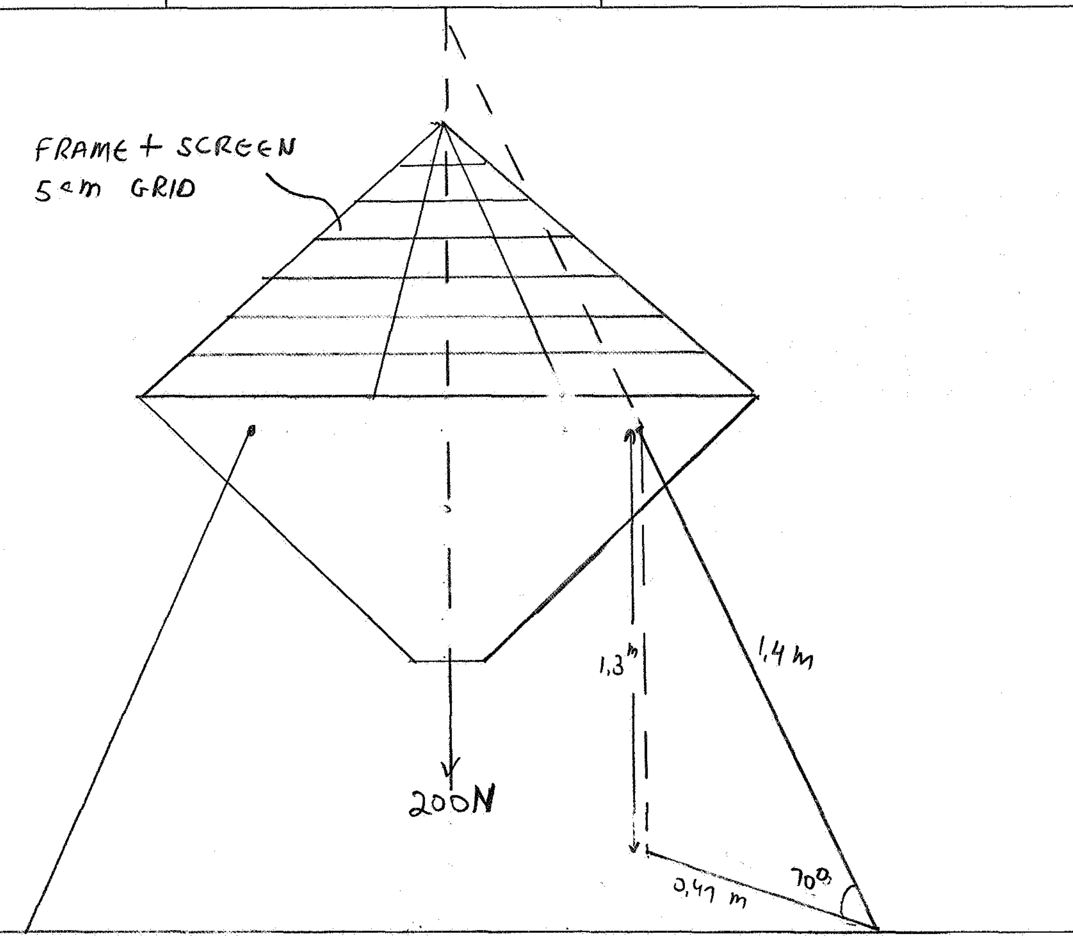
$V_{HOPPER} = \frac{1}{3}\pi r^2 h = \frac{1}{2}\pi\, 0{,}8^2\, 0.8 = 0.8\ m^3$

ASSUMING OVERLOADED HOPPER ⇒ volume of soil ≅ $1.6\ m^3$

weight of Hopper + soil $= \frac{1.6\ m^3 \times 1700 \frac{kg}{m^3}}{6} + 6.3\ kg = 150\ kg$

WITH 4 LEGS SUPPORING HOPPER DESIGN EACH LEG TO SUPPORT 50 kg.

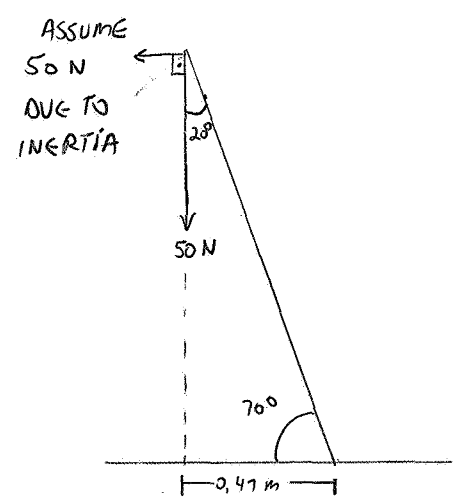
MESH ≡ 5 cm SQUAES.



FORCE ANALYSIS FOR A LEG (Hollow CIRCULAR CROSS SECTION)

FOR $d = 1''$ $t = \frac{1}{4}''$

$1'' \times \frac{1}{4}''$ $\sigma_{MAX} = \frac{MC}{I} = \frac{110\,lb \times (18{,}5\,IN + 52\,IN)\,0{,}5\,IN}{0{,}046\,IN^4} = 83\,314\,PSI$



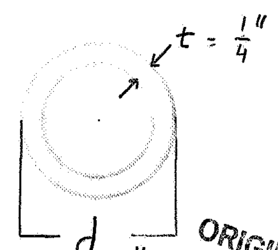
TRY LARGER SECTION!

$d = 1\frac{1}{2}''$ $t = \frac{1}{8}''$

$'' \times \frac{1}{8}''$ $\sigma_{MAX} = 25800\ PSI$

$\tau_{MAX} = \frac{2V}{A} = \frac{2 \times 140\,lb}{0{,}54\,IN^2} = 522\ PSI$

$Y_{MAX} = \frac{F\ell^3}{6EI} = \frac{140\,lb \times 55^3\,IN^3}{6 \times 10{,}3 \times 10^6\,PSI \times 0.129} = 2.9''$ DEFLECTION TOO LARGE



$'' \times \frac{1}{4}''$ TRY $Y_{MAX} = \frac{140\,lb \times 55^3\,IN^3}{6 \times 10{,}3 \times 10^6\,PSI \times 1{,}132} = 0.33''$

USE ALUMINUM ROUND TUBING

$d = 3''$ $t = \frac{1}{4}''$

$\frac{\text{WEIGHT}}{\text{m SECTION}} = 3.9 \frac{kg}{m}$. $\frac{\text{MASS}}{\text{m section}} = 0.4\ kg_{mass}$

APPENDIX E

THE HYDRAULIC CYLINDERS (MAIN CYLINDER)

MAX FORCE REQUIRED FROM ANY HYDRAULIC CYLINDER IS ABOUT 800 lb

TRY SYSTEM WITH 500 PSI

$L_i = 1\,m$

$L_f = 1.54\,m$

CYLINDER BORE = $1\frac{1}{2}$"

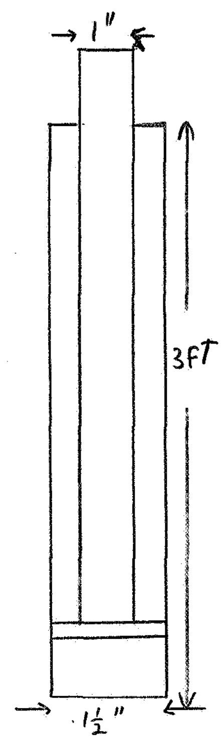
PISTON AREA = 1.767 IN^2

PUSH STROKE FORCE = 884 lb

OIL volume/IN stroke = .00765 gal.

USE 1" STEEL ROD

(USE OF STEEL ENABLES US TO USE SMALLER DIAMETER RODS WHICH COMPENSATES FOR LARGER MASS OF STEEL)



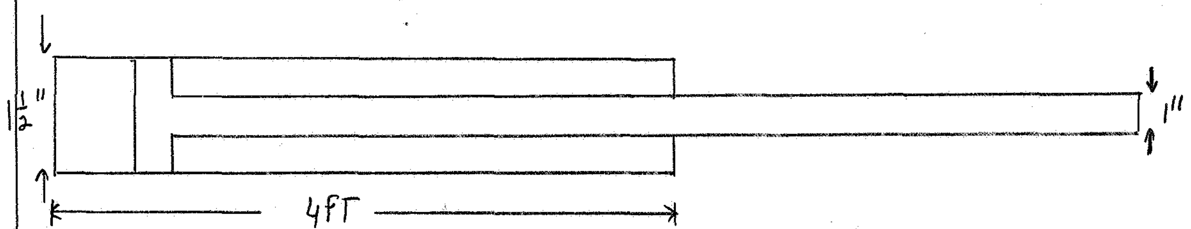
MAIN CYL.

SECONDARY CYLINDER

$L_c = 1.3$ m

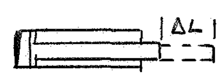
$L_F = 2.1$ m

F = 300 lb



BAG OPEN-CLOSE CYLINDER

$\Delta L \cong 5\,cm \cong 2''$



F = 10 lb

P = 500 PSi

$A = \frac{F}{P} = \frac{10\ lb}{500\ PSi} = 0.02\ IN^2$

$d_{MIN} = \frac{1}{16}''$ ⇒ USE SMALLEST CYLINDER AVAILABLE.

OR A SOLENOIDE.

HOPPER OPEN CLOSE CYLINDER

$\Delta L = 20\,cm \cong 8''$

F = ?

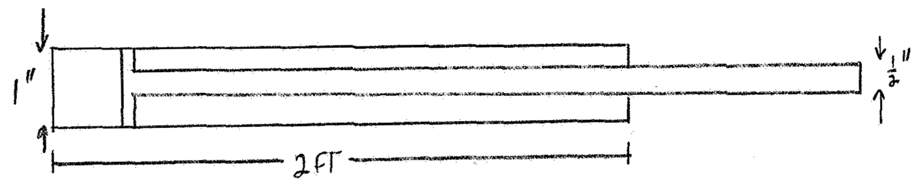
CYLINDER FOR FEEDING BAGS

$\Delta L = 1.5$ FT

$F = 50$ N (FORCE REQUIRED TO SLIDE ONE FULL BAG + FORCE TO SLIDE ZIPLOCK + FORCE TO ROTATE BAG ROLL)

$P = 500$ PSI

$A = \frac{F}{P} = \frac{50 \text{ lb}}{500 \text{ PSI}} = 0.1 \text{ IN}^2 \Rightarrow$ MIN. DIA OF CYLINDER IS ABOUT $\frac{1}{2}''$, USE $1''$ DIA



FORCES REQUIRED TO SCOOP SOIL

TO KNOW THE BENDING MOMENTS THAT THE FRAME MEMBERS MUST WITHSTAND, WE MUST FIRST OBTAIN A FIGURE FOR THE AMOUNT OF FORCE TRANSMITTED THROUGH THE SCOOPS.

FROM GARY IN DESIGN LAB: SOIL SHEARING STRESS REQ.;

$$\boxed{S = C + \sigma \tan\phi}$$

WHERE C = SOIL COHESION

ϕ = INTERNAL ANGLE OF FRICTION.

σ = SHEAR STRESS

SOME LIKELY VALUES:

$C = 1\ kN/m^2$

$\phi = 50^\circ$

$\sigma = 344.7\ kN/m^2$

$$S = 1 + 344.7(\tan 50^\circ)$$

$$\boxed{S \cong 412\ kN/m^2}$$ SHEAR STRESS OF SOIL

SINCE WE KNOW THE AREA OF THE SCOOPS, WE CAN ESTIMATE THE TOTAL FORCE REQUIRED TO SCOOP THE SOIL. THIS IS A WORST CASE APPROXIMATION SINCE THE PARAMETERS USED TAKE PACKED SOIL INTO ACCOUNT.

$$4F = (\text{EFFECTIVE SCOOP AREA})(S)$$

FOUR HYDRAULIC CYLINDERS WILL BE USED TO MOVE THE SCOOPS.

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(OVER)

THE "EFFECTIVE" SCOOP AREA IS THE CROSS-SECTIONAL AREA OF BLADE'S CUTTING EDGE.

IN THE CASE OF 1cm SCOOP THICKNESS, THE "EFFECTIVE" SCOOP AREA IS:

$$A_{scoop} = .01m * 2m = .02m^2$$

THEREFORE, THE ESTIMATED FORCE REQUIRED TO CUT THROUGH THE SOIL IS:

$$4F = (.02)m^2 * 412\ kN/m^2 = \boxed{8.24\ kN}$$

$$\boxed{F = 2.06\ kN} = 2060\ \text{NEWTONS}/\text{CYLINDER}$$

$$F = (2.06 \times 10^3 N) \times .225 \frac{lbf}{N} = \underline{463.5\ lbs}$$

$$\underbrace{2F = \underline{927\ lbs} = \underline{4120\ \text{NEWTONS}}}_{\text{FORCE EACH MEMBER WILL EXPERIENCE (TENSION)}}$$

E-4 A.

~~8.~~ 5 HYDRAULIC FORCE / POSITION CONTROL

DUE TO THE NATURE OF HYDRAULIC CYLINDERS, A MONITORING SYSTEM HAD TO BE IMPLEMENTED ONTOP THE SCOOPING MECHANISM TO ~~CONTROL~~ MAINTAIN AN EVEN MOVEMENT OF THE SCOOPS ON THEIR TRACKS.

BECAUSE THE FORCE LOADING MAY BE UNEVEN ~~DUE~~ FROM ONE END OF THE SCOOP TO THE OTHER, THE CYLINDERS WOULD TEND TO ~~WORK~~ TRAVEL AT AN UNEVEN RATE, BECAUSE THE PRESSURE WITHIN THE CYLINDERS REMAIN CONSTANT. TO ACCOMMODATE FOR THIS PHENOMONEM, VARIABLE FLOW SERVO VALVES WILL BE IMPLEMENTED INTO THE CYLINDERS TO CONTROL THE FLOW OF FLUID.

POSITION SENSORS WILL PROVIDE A SIGNAL FROM EACH PARALLEL PAIR OF HYDRAULIC CYLINDERS. THE SENSOR IS PART OF A MICROPROC. CONTROL THAT UPDATES THE POSITION OF THE CYLINDERS AND COMPARES THE TWO. IF ONE CYLINDER IS "AHEAD" OF THE OTHER, ~~IT~~ THE VALVE ~~OR~~ THAT CONTROLS ITS FLOW WILL BE CLOSED UNTIL THE MICROPROCESSOR "SEES" AN EVEN POSITION SIGNAL FROM EACH HYDRAULIC CYLINDER ~~BY USING THIS +~~ SINCE THE ENTIRE RESPONSE OF THE CONTROL SYSTEM IS OF THE ORDER OF MILLISECONDS, THE MOTION OF THE SCOOPS ~~SHOULD~~ WILL REMAIN EVEN.

(OVER)

EACH CYLINDER REQUIRES TWO SERVO-VALVE ONE FOR INPUT, ONE FOR OUTPUT FLOW. THE TOTAL NUMBER OF HYDRAULIC CYLINDERS IS FOUR, SO EIGHT SERVO-VALVES WILL BE NEEDED WITH 4 LINEAR POSITIONION SENSORS.

B. (6) STEPPER MOTORS

~~FOR PIVOTING THE SCOOP~~

TWO STEPPER MOTORS WILL BE USED TO ROTATE THE SCOOP ABOUT ITS AXIS. THE PURPOSE OF BEING ABLE TO ROTATE THE SCOOP ARE:

1. TO MAINTAIN THE LEVELNESS OF THE SOIL LOAD AS IT IS BEING RAISED.

2. TO BE ABLE TO DUMP THE LOAD AT WILL INDEPENDENTLY OF THE POSITION OF THE OTHER LINKS IN THE MECHANISM.

BY PLACING A SENSOR IN THE MAIN (PRIMARY) BEAM PIVOT, THE ANGULAR POSITION OF THE MAIN BEAM CAN BE MONITORED. CALL THE VARIABLE ANGLE OF THE MAIN BEAM θ_1. THE STEPPER MOTOR IS LOCATED AT THE SCOOP AXIS, ~~AND~~ IT REPRESENTS THE ANGLE THAT WE WISH TO CONTROL. CALL THIS ANGLE θ_2. THROUGH TRIAL & ERROR, A FUNCTION CAN BE DEVELOPED TO RELATE THE ANGLES θ_1 AND θ_2.

$$\theta_2 = f(\theta_1)$$

FEEDBACK SENSORS ~~AND~~ USING MICROPROCESSOR CONTROL CAN BE CONFIGURED TO CONTROL THE ANGULAR POSITION OF THE SCOOP (STEPPER MOTOR).

(OVER)

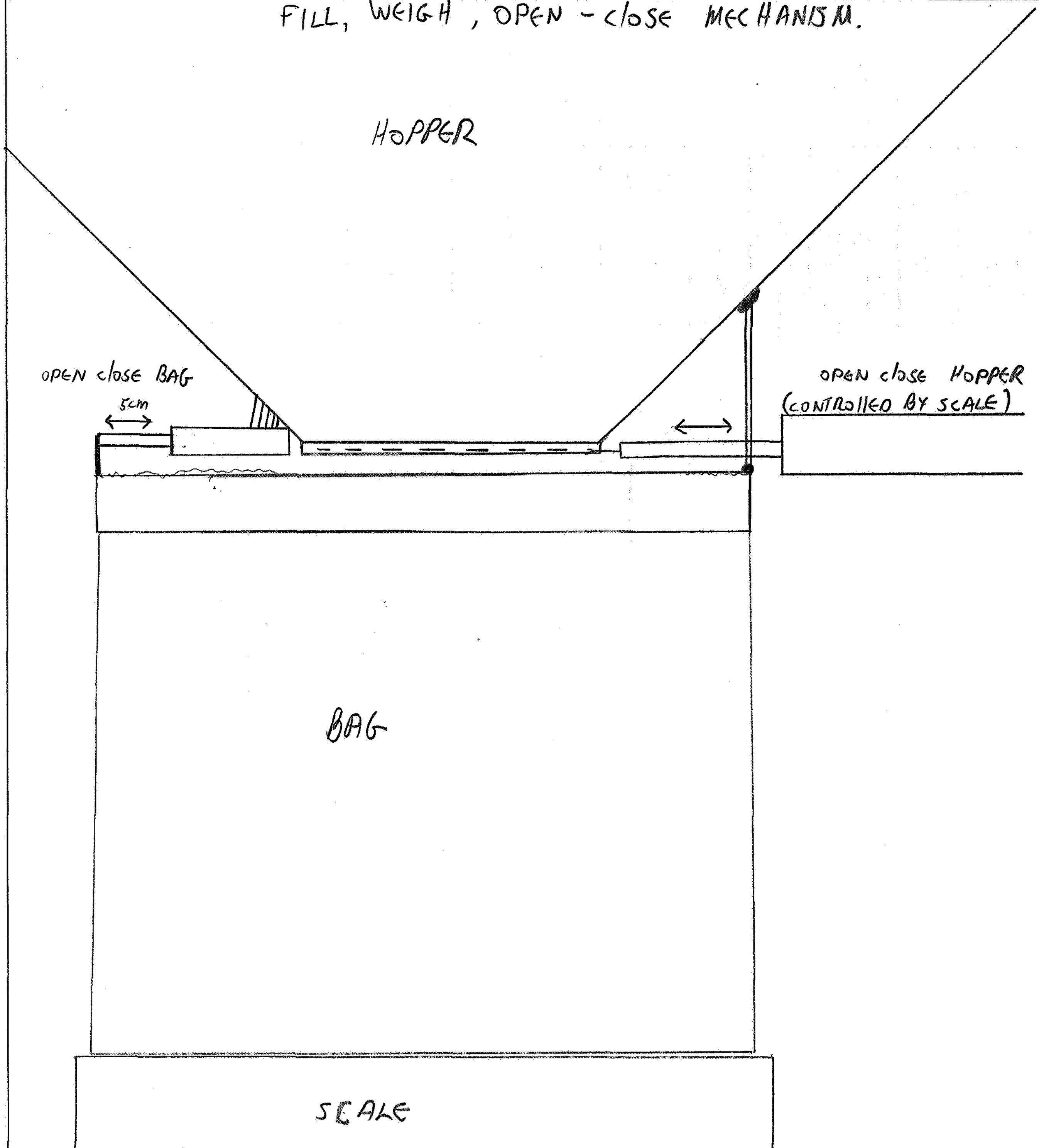
A TYPICAL HIGH RESOLUTION STEPPER MOTOR HAS UP TO 25,000 "STEPS" PER REVOLUTION, MEANING THE ACCURACY IS TREMENDOUS.

TYPICAL WEIGHTS OF EACH STEPPER MOTOR IS 7.9 lbs (35.0 NEWTONS)

APPENDIX F

Appendix F

FILL, WEIGH, OPEN-close MECHANISM.

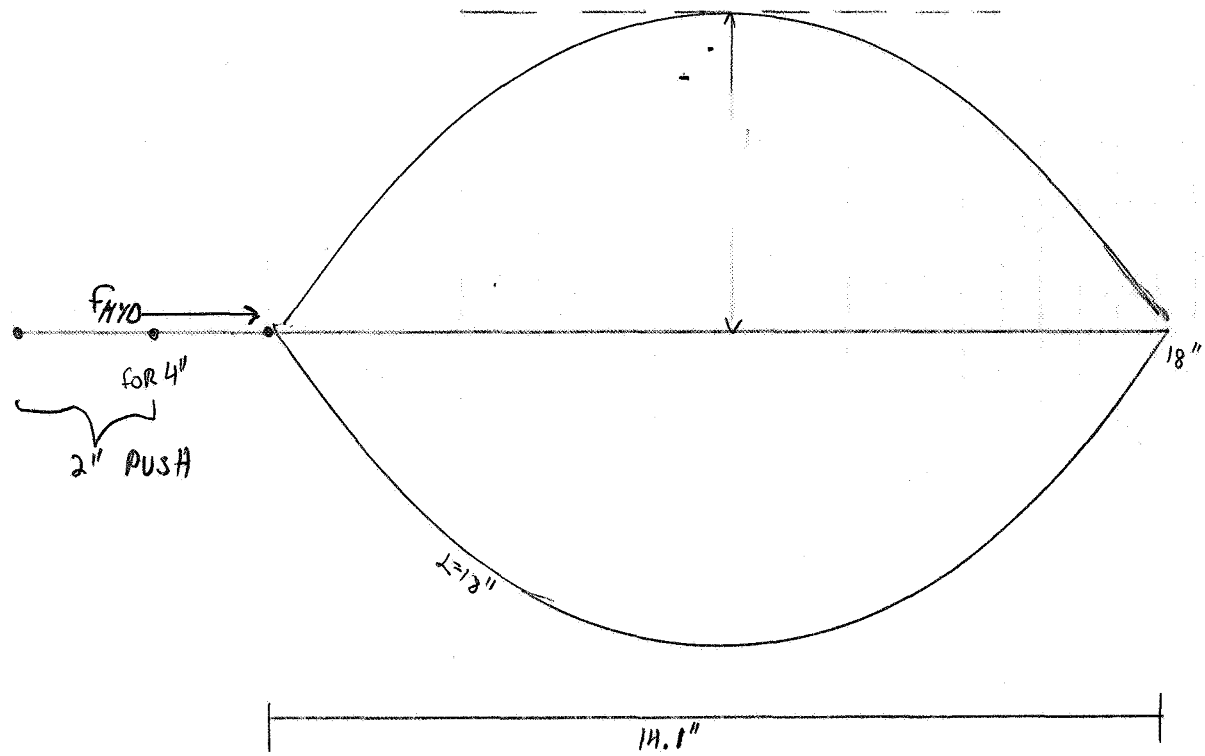


OPEN CLOSE MECH.

* USE ZIP LOCK BAGS. (NEED TO FIND SUFFICIENT SIZE)
* SLIDE BAG ON TWO PARALLEL THIN STEEL BARS ON EACH BAR A CHANNEL SHAPED TO HOLD THE ZIPLOCK.
* PUSH RODS WITH HYDRAULIC CYLINDER TO OPEN BAG.
* OPEN HOPPER AND FILL BAG WITH SOIL. TO SPECIFIED WEIGHT.
* CLOSE HOPPER AND BAG.
* PULL BAG AND SEAL IT.
* CUT BAG FROM LINE

ONCE SUITABLE MATERIAL FOR CHANNELS IS FOUND FORCED REQUIRED TO OPEN THE MECH. AND TO PULL BAGS CAN BE FIGURED.

OPEN close MECHANISM.



$$y_{max} = \frac{Fl^3}{48EI} \Rightarrow F = \frac{y_{max}}{l^3} \times 48EI = \frac{4 \times 48 \times 27.6\times10^6 \times 4.1\times10^{-6}}{18^3} = 3.72 \text{ lb}$$

$$I = \frac{bH^3}{12} = \frac{1.5'' \times 0.032^3 \text{ IN}^3}{12} = 4.1 \times 10^{-6} \text{ IN}^4$$

THE EQUIVALENT TO THE HYDRAULIC FORCE WHICH NEEDS TO BE APPLIED AT CENTER OF BEAM IS 4.7 lb

$F = 4.7 \text{ lb}$

$$m = F\frac{x}{2} = 3.72 \times 4 = 15 \text{ IN-lb}$$

$$\sigma_{max} = \frac{MC}{I} = \frac{15 \text{ INlb} \times 0.016 \text{ IN}}{4.1\times10^{-6} \text{ IN}^4} = 0.59\times10^5 \text{ psi} = 59 \text{ kpsi} < 70 \text{ kpsi}$$

$$\tau_{max} = \frac{3V}{2A} = \frac{3'' \times 4.7 \text{ lb}}{2 \times 0.032'' \times 1.5''} = 220 \text{ psi}$$

USE EULER COLUMN ANALYSIS TO FIND F_{HYD}

$$P_c = \underset{\substack{\uparrow \\ \text{Two} \\ \text{Columns}}}{2}\ \frac{\pi^2 E I}{\ell^2} = \frac{2 \times \pi^2 \times 27.6 \times 10^6 \text{ psi} \times 4.1 \times 10^{-6} \text{ IN}^4}{18^2 \text{ IN}^2} = 7 \quad \overset{P\quad A}{\text{psi} \times \text{IN}^2}$$

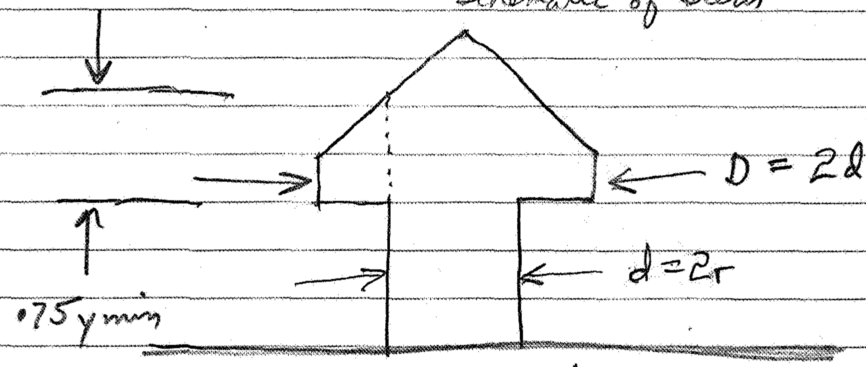
$F_{HYD} = 7$ lb = FORCE REQUIRED TO OPEN BAG.

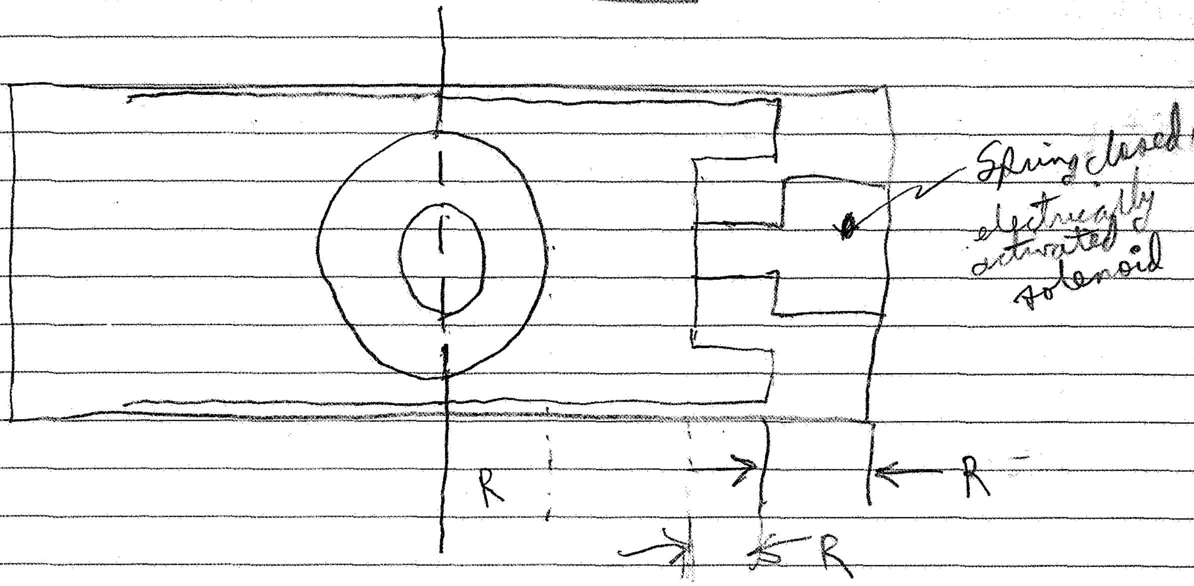
APPENDIX G

Appendix G Interface Mechanisms

1.75 m TRIANGLE

Schematic of Stem

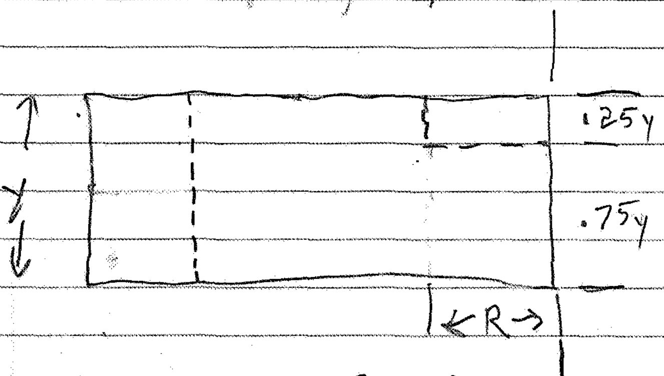




material = 2014 T6 Aluminum

W = Weight of implement

$$\boxed{r_{min} = .3989\left[\frac{W}{\sigma_{ys}}\right]^{1/2}} \quad \text{safety factor} = 1.5 \text{ on } W$$



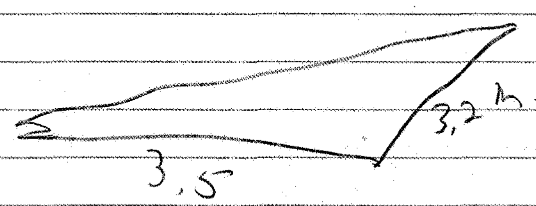
using pure shear theory:

eg: Punch out (way overdesigned)

$$\left[(.75y)\ \pi R\right]\tau_{xy} = .75\,W \qquad \tau_{xy} = \frac{\sigma_{ys}}{2} \qquad \boxed{S.F = 1.5 \text{ on } W}$$

$$\cancel{.75}\,y\,\pi R\,\frac{\sigma_{ys}}{2} = \cancel{.75}\,W$$

$$\boxed{y = \frac{2W}{\pi R \sigma_{ys}} = \frac{2}{\pi R}\left[\frac{W}{\sigma_{ys}}\right]}$$


3,2 m
3,5

OVERALL WEIGHT OF SOIL BAGGER

	MAS/m $\left(\frac{N}{m}\right)$	m	MASS (KG)	W_{EARTH}	W_{MOON}
FRAME BEAMS	1.3	20	26		
PIVOT BEAMS (2)	1	2	4		
MAIN BEAMS (2)	1	8	16		
SEC BEAMS (2)	.3	4	2.4		
MAIN CYL (2)	5		10		
SEC CYL (2)	5		10		
HOPPER.	15		15		
LEGS (4)	0.4	1.4	2.3		
SCREEN + MESH			2		
BAG OPEN-CLOSE CYL.			1		
" " " BAR (2)			1		
HOPPER OPEN CLOSE CYL.			1		
BAG FEED CYL.			2		
LASER CUTTER.			1		
INTERFACE + 4 LEGS	1	20	25		
HYDRALIC SYSTEM (- CYLINDERS)			10		
CONTROL SYSTEM.			3		
POWER SYSTEM.			10		
POWER SUPPLY			?		
SCOOP			30		
(Turn Table + Rod)			175 kg	1500 N	250 N

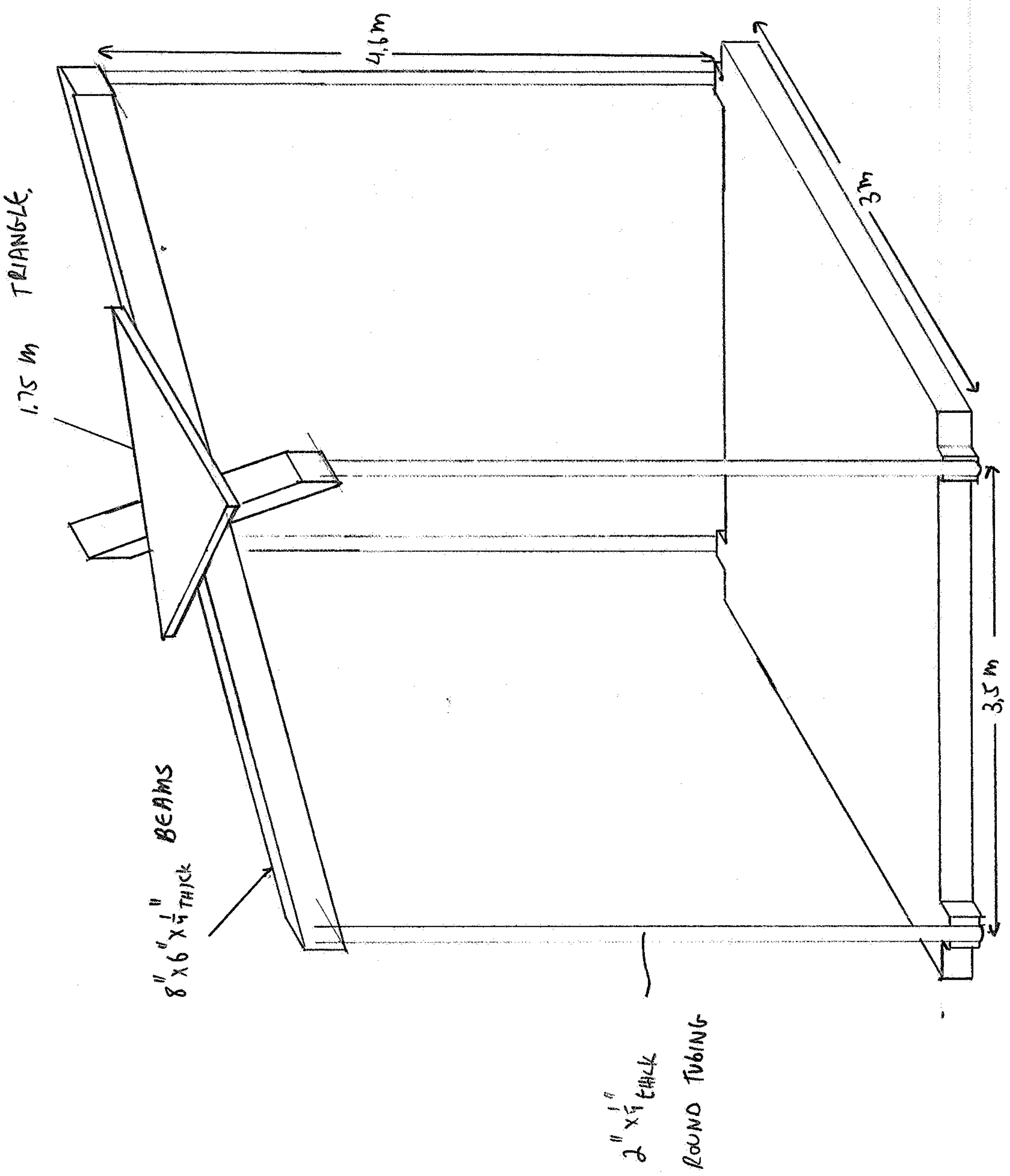
ORIGINAL PAGE IS OF POOR QUALITY

WEIGHT OF WHOLE MACHINE

1750 N EARTH	300 N MOON

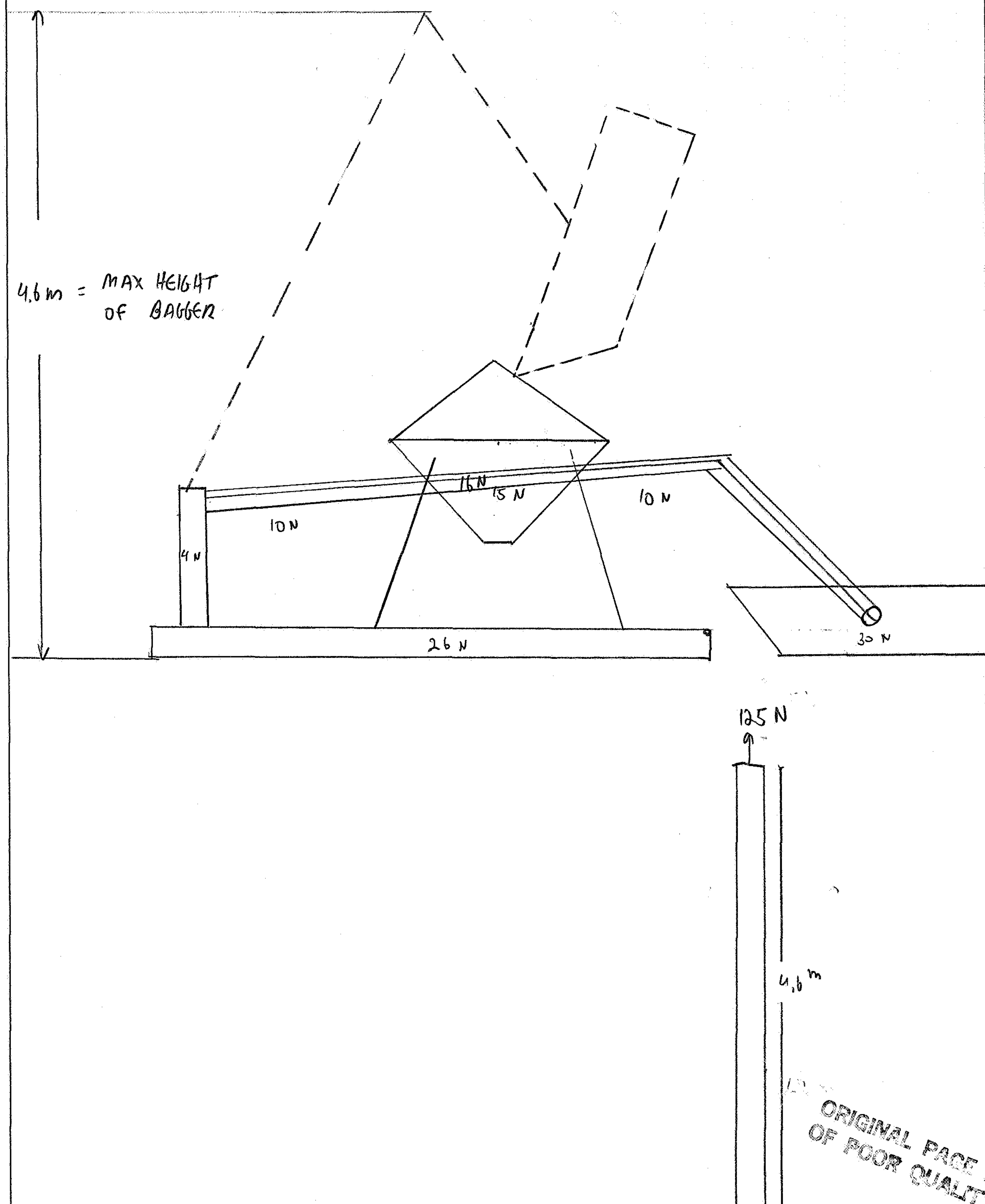
FOR CALC. OF FORCES ON MACHINE SUPPORTS USE 500 kg

CONNECTION OF BAGGER TO SKITER



CONNECTION OF "BAGGER" TO "SKITTER"

LEVEL OF INTERFACE = 5 m.

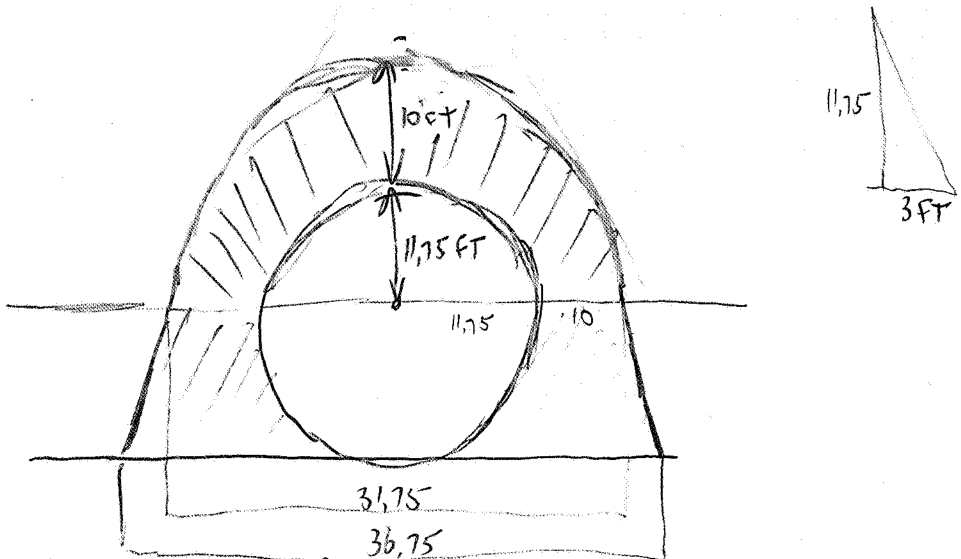


APPENDIX H

IND. TAPE AND SUPPLY CO. 2194B Marietta Blvd. 800-323-TAPE

CATALOG THOMCAT Vols 15-21

STAR PACKAGING CORP 763-2800 college park



$$\frac{\pi \times (21{,}75^2 - 11{,}75^2)}{2} + \left(\frac{31{,}75 + 36{,}75}{2}\right) 11{,}75 - \frac{\pi \times 11{,}75^2}{2} =$$

$$\frac{34.33 \text{ FT}^3}{1 \text{ m}^3}$$

$$A_{shaded} = 526{,}3 + 402{,}5 - 217 = 711{,}8$$

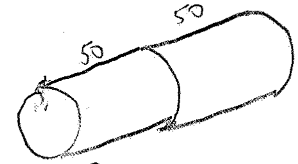
cover Faces

$$712 \times 50 + 2 \times \left(\frac{\pi\, 21{,}75^2}{2} + 11{,}75 \times \frac{31{,}75 + 36{,}75}{2} \right) \times 10 =$$

3,25

$$35600 + 20(743 + 402)$$

$$35600 + 22910 = 58509 \text{ FT}^3$$



IF separate Need $\approx \frac{360 \times 10^3 - 420 \times 10^3 \text{ FT}^3}{18 \text{ month}}$

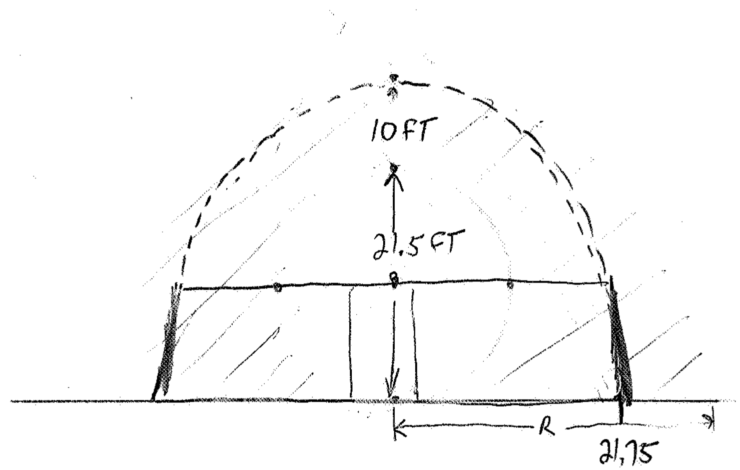
IF combined in Line Need $\approx \frac{236 \times 10^3 - 272 \times 10^3 \text{ FT}^3}{18 \text{ month}}$

WORST 780 FT^3/day , Best 440 FT^3/day

IF $3 \times 2 \times \frac{1}{2} \Rightarrow 3 \text{FT}^3 \Rightarrow 260$ Bags

1) LUNAR ARTHROPOD PLATFORM
2) " DIGGING
3) " CRANE
4) " DRILL
* 5) " SOIL BAGGING
6) " CARGO INTERFACE

BAG SIZE.
BAG MATERIAL.
WAY TO LOCK.
NO. OF BAG/hr.



$R = 31.5$ FT $A = \frac{\pi \times 31.5^2}{2} - \pi \times 11.75^2 = 1125\ FT^2$

For a 50 FT section will need

$1125 \times 50 + 2 \times 10 \times 1557 = 87{,}430\ FT^3$

$1125 \times 50 \times 6 + 4 \times 10 \times 1557$ 28200 FT^3 with front covered.

If a Bag is $2' \times 1' \times \frac{1}{2}' = 1\ FT^3$

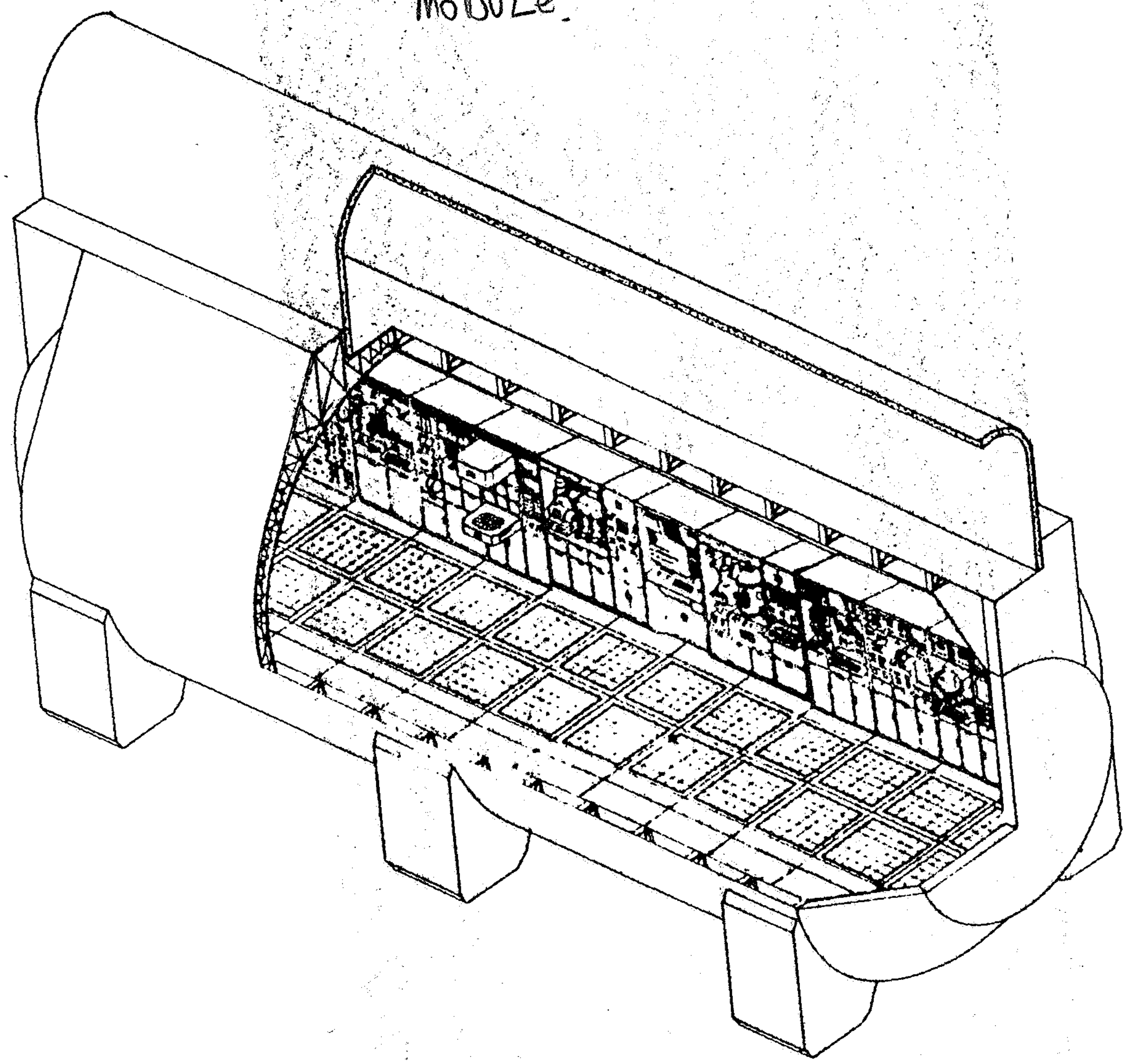
we will need 23000 Bags. (without covering front)

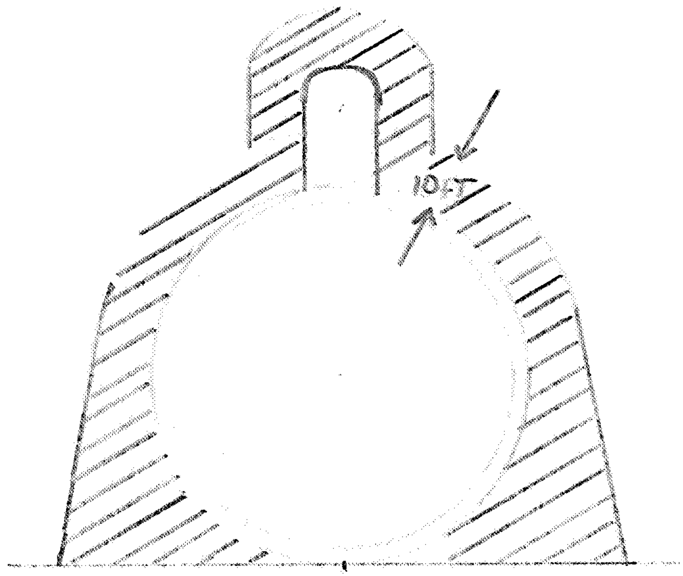
If the machine will fill 500 Bag/hr

it will take 2 full day of working. 24 hr/day.

with front " " " " " " " " "

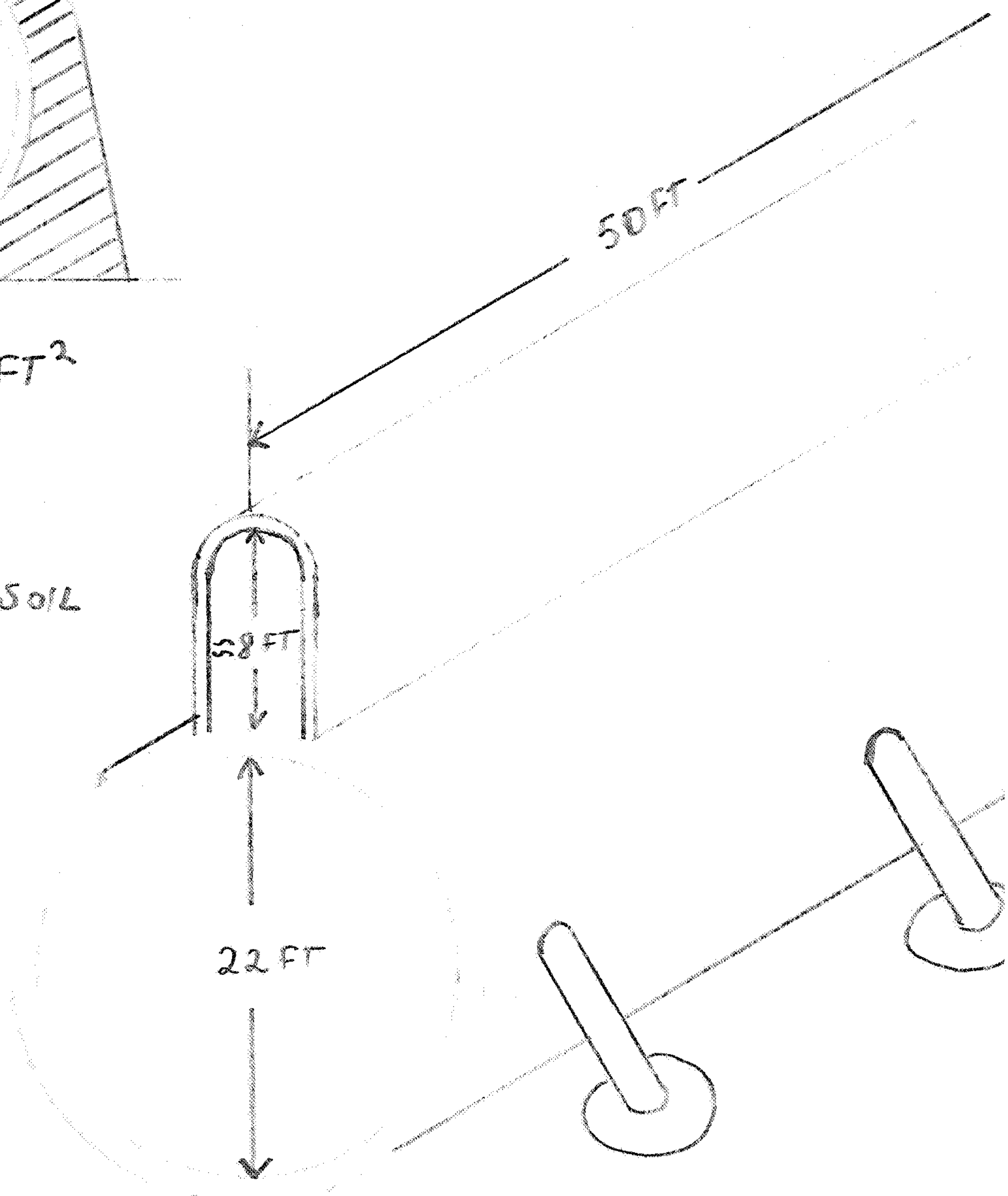
MODULE

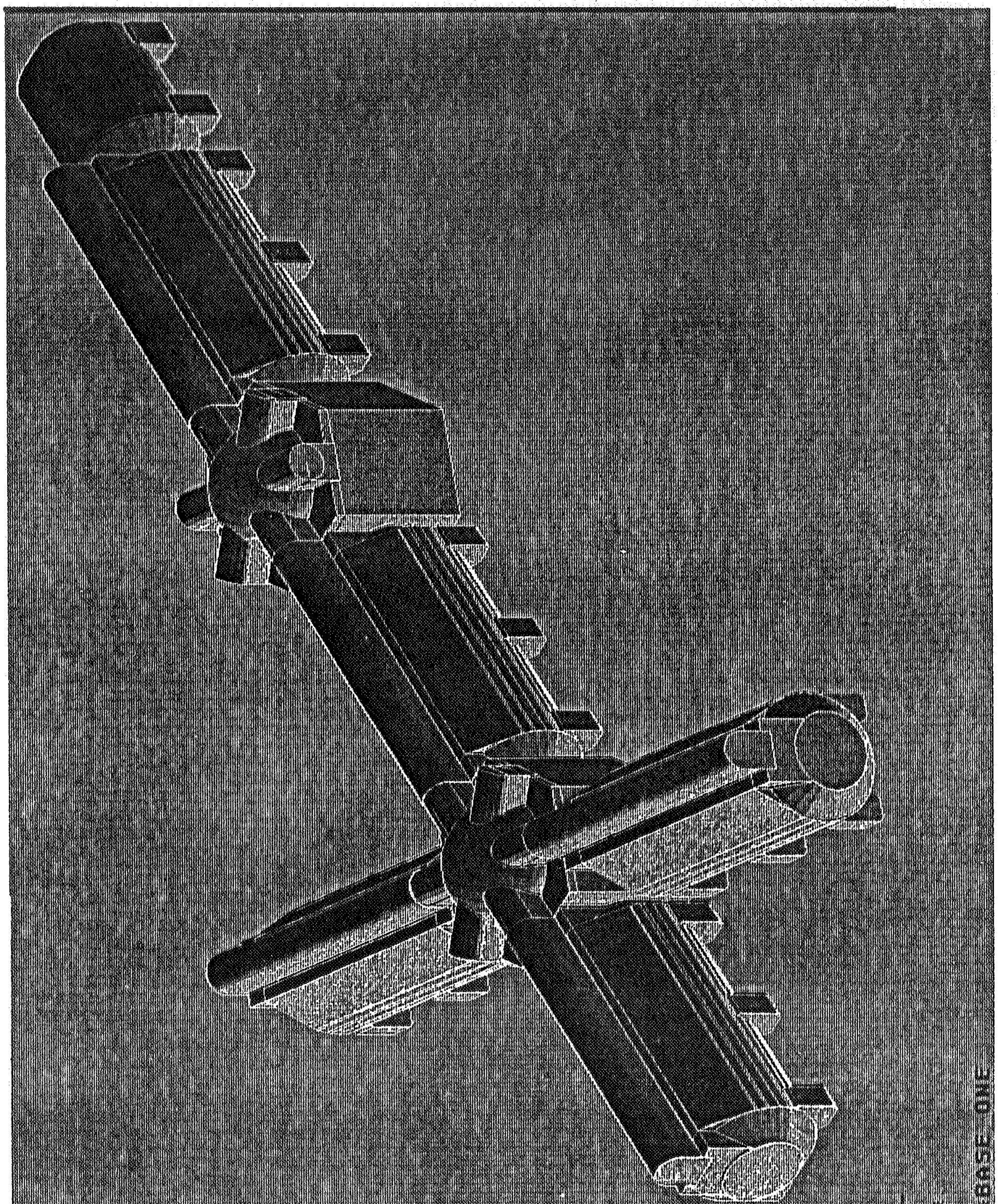


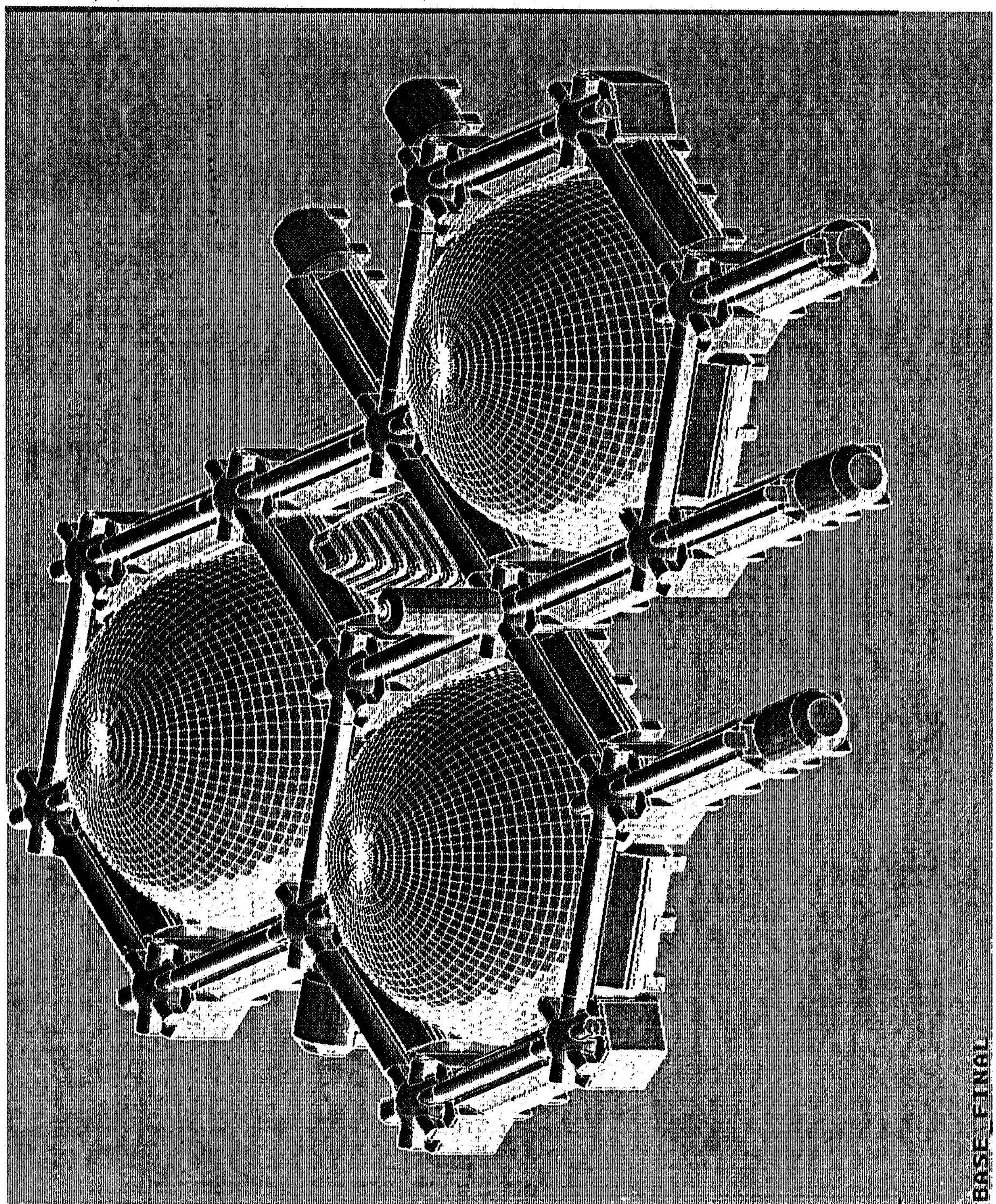


HADED AREA ≈ 750 FT^2

TO COVER PHASE I
NEED ≈ 500,000 FT^3 SOIL




BASE ONE


BASE_FINAL

GOING IN APPENDIX

DESIGN AND DEVELOPMENT OF TRANSPORT MECHANISMS FOR "BAGGING" LUNAR SOIL FOR USE AS RADIATION SHIELDING

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Center for Experimental Architecture
College of Architecture, University of Houston
Houston, Texas 77004

FORWARD

The concept of "bagging" lunar soil for protective shielding as presented here is currently being developed within the context of a larger research endeavor known as Project L.E.A.P., in cooperation with the University of Houston's Center for Experimental Architecture and NASA's Johnson Space Center, Solar System Exploration Division and the Advanced Projects Office. Project L.E.A.P. stands for Lunar Ecosystem and Architectural Prototype, and is a design for a manned lunar base with a focus on the architectural issues of a lunar settlement in an Earth-Moon space infrastructure. Under investigation are design studies for an initial lunar base, which can serve as the core facility for larger lunar settlements as needs and activities evolve. It is an objective of Project L.E.A.P to provide the "Lunar Initiative" a reference lunar base configuration, whereby, lunar research working groups which are developing specific systems for lunar bases will then have available to them a design reference based on a realistic growth scenario. It is within the framework of Project L.E.A.P. that the bagging concept is presented.

SUMMARY

This paper outlines a concept for design and development of a system for automating the process of collecting lunar soil and placing the soil in bagged form over habitation modules of a lunar base for use as radiation, meteoroid, and thermal protection. High cosmic radiation levels, hypervelocity meteorite particles and extreme temperature shifts corresponding with permanent settlement of the lunar surface significantly impacts functional lunar base design as well as strategies of construction and choice of materials for initial bases and subsequent growth of the settlement. A logical approach to provide shielding protection is to cover habitation facilities with lunar regolith. It is estimated that a dense layer of material, 2 to 3-1/2 meters of soil mass, can potentially limit crew radiation exposure to acceptable levels, provide outstanding meteoroid shielding, and offer thermal insulation to avoid significant temperature fluctuations. The massive amount of regolith required for this approach, however, implies heavy construction activity under hostile environmental conditions during the excavation and movement of soil and relocation of berms as the lunar base expands and makes improvements to facilities. Presented here are preliminary design criteria for Soil Particle Aquisition and Containment ("Soil-PAC") technology which can lead to the creation of an automatic system to collect regolith and put it in bags to substantially reduce crew EVA (Extravehicular Activity) time, accomplish dense packing to optimize shielding value, and facilitate easy handling with little dust.

ENVIRONMENTAL CONSIDERATIONS

Long-term Cosmic Radiation Exposure

High costs of transporting people to and from the Moon will make it essential to extend duty periods as long as possible. This will impose stringent countermeasures to limit human cosmic radiation exposure to allowable limits. Since the Moon has no radiation-absorbing atmosphere or magnetic field to deflect radiation transport of cosmic ray nuclei these safeguards must be given top priority attention. Means will be required to minimize crew exposure to these radiation hazards during both EVA and IVA (Intravehicular Activity) periods. The permissable annual maximum radiation dose set for the general public by the R.B.E. committee to I.C.R.P. and I.C.R.U., (1963) is .5 rem. The maximum permissable annual dose set for occupational radiation workers is 5 rem for any one year. For a few astronaut volunteers over 30 years of age, the Radiobiological Advisory Panel has permitted higher dosages of an annual exposure of 38 rem and a lifetime limit of 200 rem. The annual radiation dose equivalent within the upper meter of the lunar surface is approximately 30 rem during times of solar minimum. During solar flare periods which happen approximately every 11 years the radiation level can approach as much as 1,000 rem. It is estimated that during solar minimum periods, workers on the lunar surface may work approximately 10 hours per 24 hour interval during two-week-long lunar days, or 20% of the the total time EVA. Shielding habitats with a protective overlayer of lunar soil to overcome radiation hazards during IVA periods requires a provision of 400 g/cm^2 of regolith. This is approximately 2 meters of densely packed soil to limit annual radiation exposure to 5 rem during solar minimum. A provision of 700 g/cm^2, approximately 3-1/2 meters of soil will be required for the same protection during solar flares.

Meteoroid Hazards

Metoroids that would burn up or be slowed down considerably in the Earth's atmosphere are unimpeded in lunar vacuum and strike at velocities of 5 km/second - 20km/second. The energy impact is so great that the meteoroid explodes and vaporizes, excavating a mass of material up to 1,000 times that of the projectile. While no particles of destructive size struck the Lunar Module or astronaut space suits during an Apollo mission, tiny micrometeorite impacts observed in face masks offer indicators of potential risks to permanent facilities where probabilities of more significant hits are substantially increased. Placement of pressurized habitat hulls and propellant storage tanks under a thick layer of regolith can afford significant meteoroid penetration shielding.

Temperature Extremes

Temperatures on the lunar surface can pass through an extreme range as daytime changes to night (as much as +200 F to -250 F). Extreme temperature ranges or high temperature constants present problems for maintaining long-term operability of surface equipment. Lubricants necessary to keep equipment such as mining and transport devices operable under abrasive conditions posed by fine lunar dust may solidify or boil away due to prolonged exposure to heat/cold. Flexible membranes may tend to become brittle due to cold or age rapidly due to heat.

DESIGN AND OPERATIONAL CONSIDERATIONS

Mission Requirements Influencing Concept Applicability

Mining and processing of ilmenite to obtain oxygen for consumption in space is proposed as the primary mission activity of the reference lunar base design of Project L.E.A.P. Throughout the development of the lunar base, experimentation in the areas of medicine, chemistry, astronomy, physics, geology, materials processing, fabrication methods, and agriculture will take place in order to better understand the effects of the lunar and space environment on these areas of interest, especially as they relate to the process of utilizing lunar resources for self-sufficiency. Construction of living and experiment facilities is achieved incrementally over a ten year period beginning in the year 2005, and evolves from a ten-person crew capability to a thirty-person level of permanent personnel support by the year 2015. An advanced base is eventually realized capable of accommodating up to a hundred-and-fifty people for habitability.

Major challenges in the development of the reference lunar base that are addressed by the Soil-PAC concept include problems posed by transportation constraints, mission requirements and evolutionary growth.

Transportation Constraints. High costs and competition for volume/weight associated with transporting people, equipment and materials to the Moon will necessitate use of available lunar resources in as simple and direct a manner as possible. Soil-PAC technology embodies a concept that enables the abundant lunar regolith to be easily and efficiently collected, packaged and utilized to form protective blankets over habitats and storage units as well as provide "building blocks" for constructing shielding walls and enclosures, (Fig. 1).

Mission Requirements. Means to minimize astronaut EVA time (and radiation exposure) for mining, construction and equipment servicing will be an urgent priority. The Soil-PAC concept easily lends itself to automation to minimize EVA requirements. Concept simplicity can optimize equipment and process reliability to reduce time, parts and skill requirements for equipment servicing and repairs. It should also facilitate effective manipulation by astronauts encumbered by EVA pressure suits.

Evolutionary Growth. Achieving large volumns of space within a relatively short period of time, and with minimum requirements for construction processes is a major objective in the overall growth plan of the core base. This is

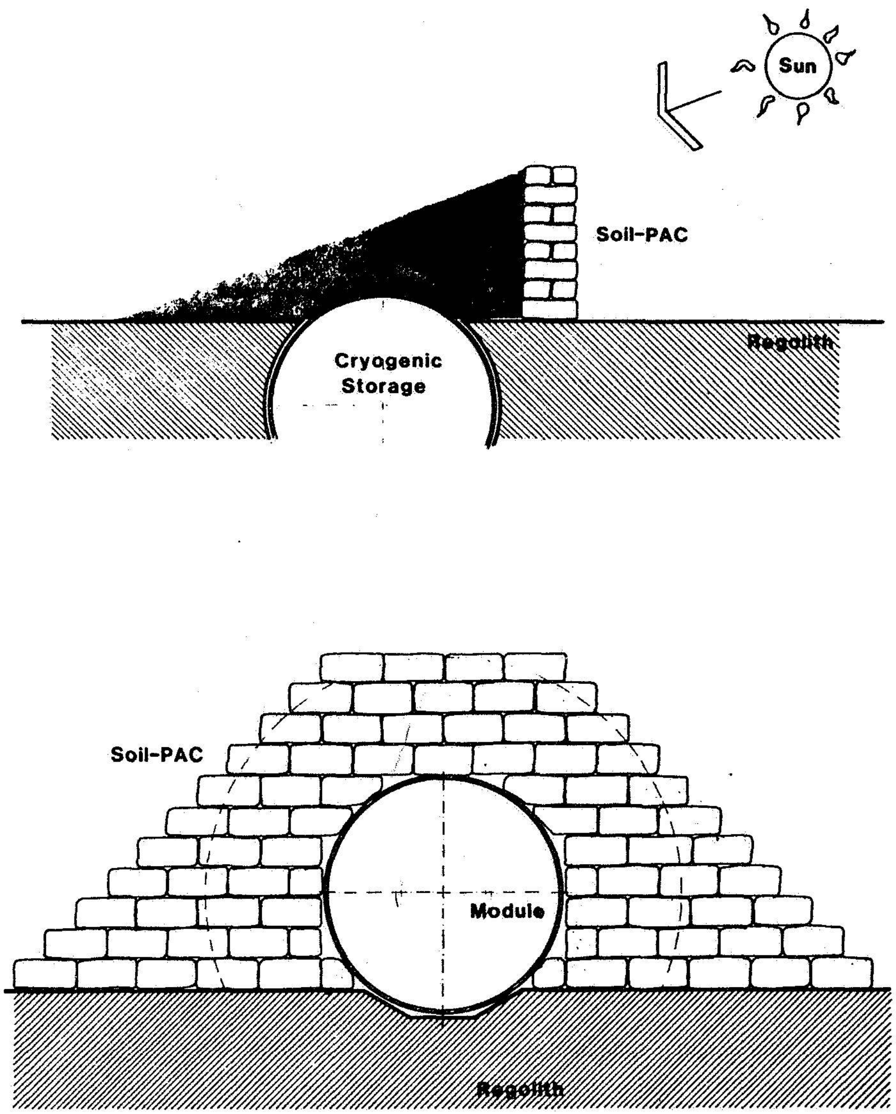
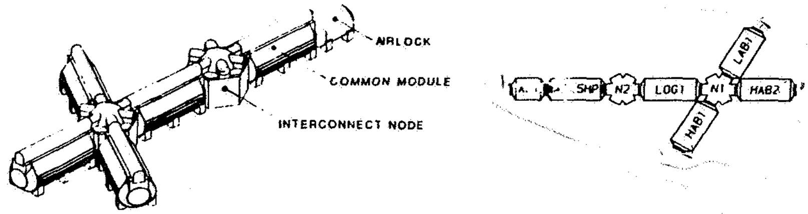


Fig. 1

accomplished in part by a planned deployment of three basic module components which will determine the eventual layout of the facility. These three components, the common module, the interconnect node, and the airlock are delivered to the lunar surface according to a growth scenario dictated by increased personnel needs and operational readiness of base functions. Due to the hexagonal design of the interconnect node a "circle the wagons" approach allows the common modules to form perimeters of floor space which can be enclosed with inflatable domes. The resulting geometry develops a honeycomb pattern of volumetric growth that evolves in stages over the ten year period to produce dedicated areas for habitation, laboratories, and farming/life-support functions, (Fig. 2 thru 7). Use of the Soil-PAC concept to shield individual and connected habitat modules accommodates architecture expansion and modification throughout the evolutionary growth stages of the lunar base. Soil-PAC technology offers direct application to support base growth at all evolutionary stages. It can provide a rapid and simple means to protect habitat modules and equipment when the initial base camp is being established. Concept flexibility is enhanced by features that enable lunar base facility components to be easily changed/reconfigured as evolutionary demands dictate.

Fig. 2

PHASE ONE LUNARBASE 2005 - 2006.5



x 800,000 FT³

Fig. 4

PHASE TWO LUNARBASE 2006.5 - 2008

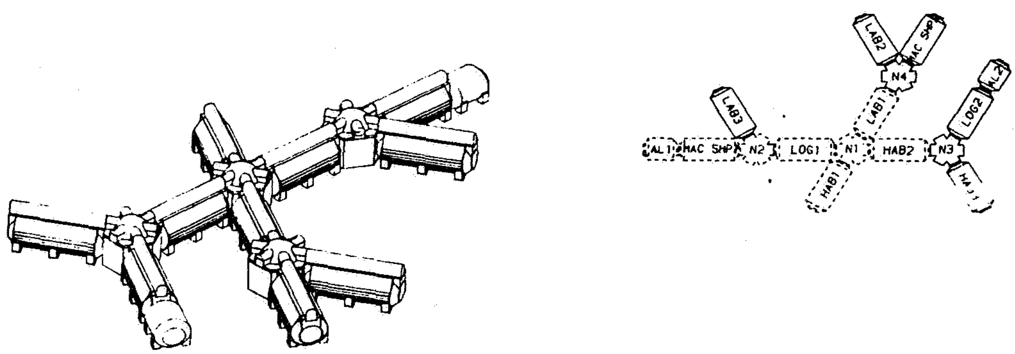


Fig. 3

PHASE THREE LUNARBASE 2008 - 2010

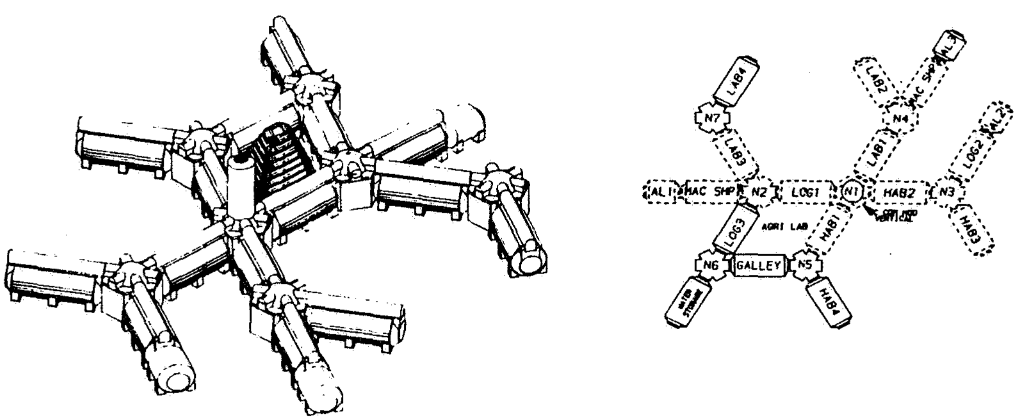


Fig. 5

PHASE FOUR LUNARBASE 2010 - 2012

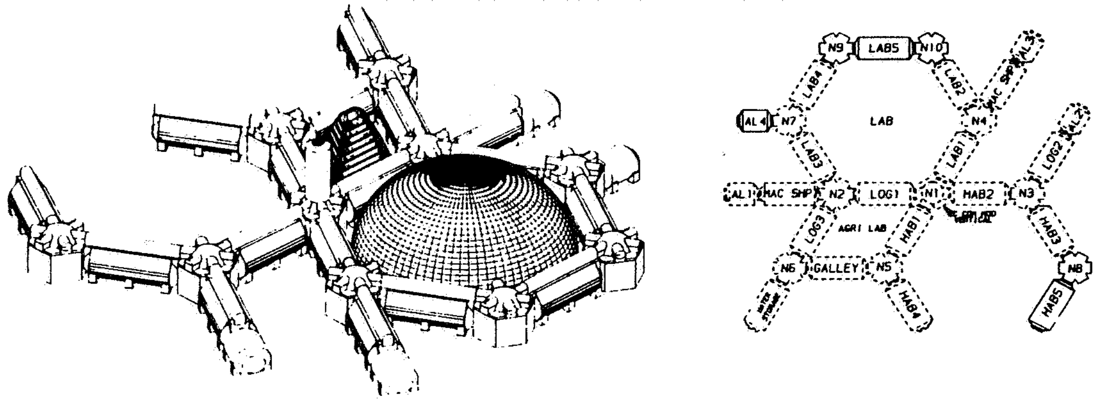


Fig. 6

PHASE FIVE LUNARBASE 2012 - 2013.5

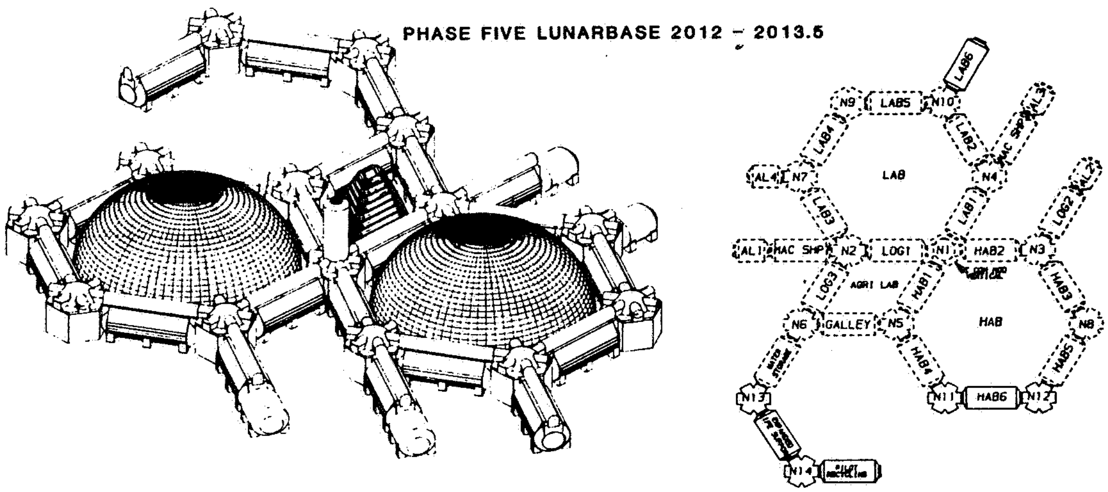
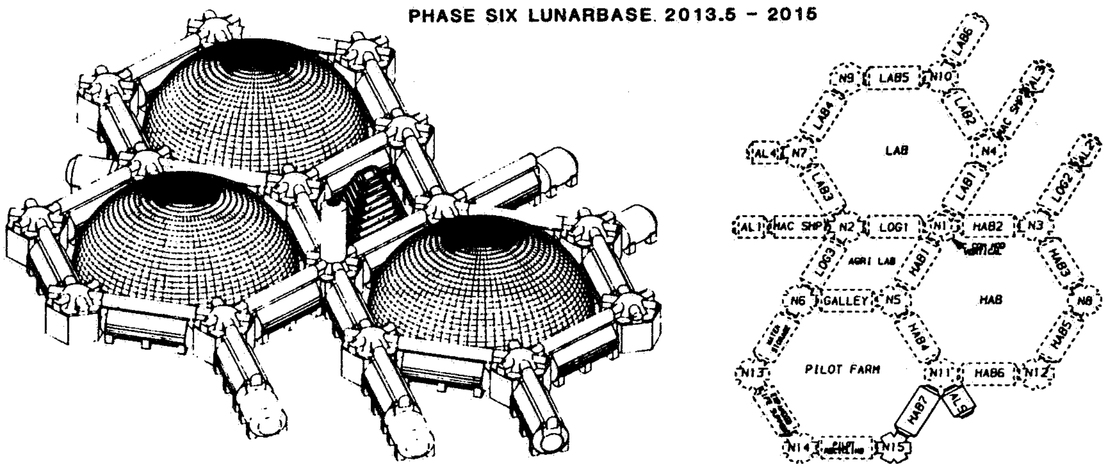


Fig. 7

PHASE SIX LUNARBASE 2013.5 - 2015



Determine Operational Requirements

Design processes and feasibility assessments will require an understanding of construction and shielding priorities that will be influenced by material availability, logistics operations, man-systems constraints and evolutionary developments.

Material Availability Studies. What lunar materials are most likely to be available to offer shielding protection? How accessible are these materials likely to be? The composition/mix of bagged regolith particles will significantly influence cosmic radiation shielding features and total mass/unit area of barrier material required for protection. Analysis of the relationships between lunar material composition/density and radiation penetration/absorbption, considering both primary and secondary transport effects must be taken into consideration.

Lunar soil mechanics investigation should begin with a review of information obtained through unmanned Surveyor Surface Sampler missions and the manned Apollo missions. The Surveyor missions produced soil mechanics data from foot pad interactions; lunar soil photography; and bearing capacity, impact, and trenching tests. The Apollo 11, 12, 14 and 15 missions provided opportunities for trenching, gathering cores, and conducting penetration tests in addition to returning samples for tests later conducted on Earth.

System design must take a variety of soil conditions into account. For example, the Surveyor and Apollo missions determined that depth and contents of lunar regolith varies significantly with location. Four general groups of particles were found in the soil: Apollo 15 soils contained the greatest proportion of mineral fragments (38%) and Apollo 14 the least (9%). Apollo 12 soils contained the greatest proportion of glasses (35%) and lithic fragments (27%). Apollo 14 soils contained the highest proportion of agglutinates (52%). Agglutinates are produced from impact strikes which "weld" soil particles together, thus creating big soil particles from small ones. Since they tend to be fragile, soils containing a large amount of this material will break up at higher confining pressures. If the bagging system were designed such that it required compacting soil to a high density, the use of a soil with a high concentration of agglutinates would have to be a determining parameter in the mechanisms of the system design.

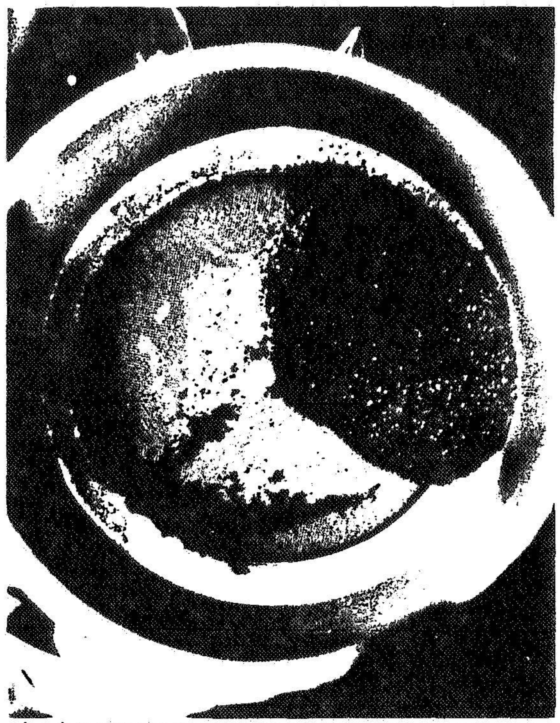
Logistics Operations Studies. What special equipment considerations must be taken into account in designing for system reliability, autonomy and safety? What servicing and repair operations must be planned for? Special equipment design requirements associated with soil mechanics, environmental conditions and servicing must be understood and correlated with candidate excavation and bagging approaches. The adhesive qualities of soils, for example, will influence the extent to which trenched walls collapse following an excavation pass. Soil depth and density will influence excavation penetration parameters and site size (shallower penetrations require larger material source fields for given total yield quantities). Soil particle size and weight will influence bag loading and compaction for desired densities, (Fig. 8).

Lunar environmental conditions which will vary with site locations will effect the operation, design life, and servicing of equipment. Surface temperature extremes ranging from as much as +200 F to -250 F must be accommodated in selection of materials, lubricants and operational devices. Moving parts must be protected from fine abrasive dust particles that cling to all exposed surfaces. Micrometeorite bombardment must be prevented from wearing away exposed thermal control coatings, sandblasting optical/transparent surfaces, and damaging electrical contacts/components. Radiation-sensitive materials and electrical components must also be protected.

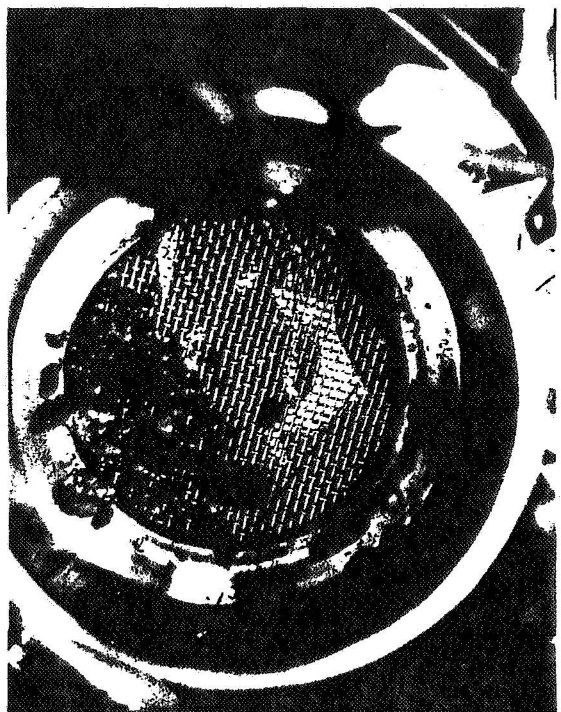
Man-Systems Studies. What roles can and should people play in these processes? What support features and safeguards will be required? Manned operations will be impeded by the hostile lunar environment, space suit constraints, and diurnal cycles. Manned operation priorities to be considered and planned for include system programming, performance monitoring, bag resupply, and periodic/emergency maintenance.

Engineering requirements to facilitate manned procedures and safety should be analyzed, and design guidelines for manned operations and safeguards should be developed as a basis for postulating and evaluating system engineering options.

Operational procedure scenarios should be modeled to establish a basis for defining allowable EVA timetables for generic operational tasks; special dexterity and lifting considerations associated with lunar gravity and space suit limitations; and potential hazards imposed by equipment operation and repair procedures.



(a) PARTICLE SIZE COARSER THAN 0.177 mm



(b) PARTICLE SIZE COARSER THAN 1.00 mm

(c) PARTICLE SIZE COARSER THAN 0.105 mm

(d) PARTICLE SIZE COARSER THAN 0.044 mm

Fig. 8 LUNAR SOIL PARTICLE SIZES (NASA PHOTOS)

Evolutionary Development Projections. How will evolutionary growth of the lunar facility influence architecture and shielding priorities? How can these developments be planned for and accommodated through Soil-PAC technology and applications? Considerations should include means and requirements to accomplish bag transport and stacking; stacking depths to provide acceptable shielding protection; and stacking geometries. Design studies should be undertaken for ways that bags can be removed/reconfigured to accommodate the architecture expansion and modification of the lunar base and how the evolutionary growth stages might influence bag sizing and engineering.

Assess Technical Options

State-of-art information about existing technology systems can potentially be applied for lunar material excavation, bagging, mobility/control and power.

Lunar Material Excavation. How will lunar gravity and soil conditions influence operation of conventional Earth excavation equipment? What modifications in basic principles and/or design refinements will be required? What manufactured systems come closest to meeting these requirements?

Bagging. What available means exist for packing soil materials in bags/bales? How will these principles and designs be influenced by lunar gravity and soil conditions? How can materials be packed in controlled densities to optimize shielding benefits? How can bags be continually provided/replenished? What materials should the bags be made of to optimize packing, shear strength and durability? How large should the bags be to facilitate machine and man handling operations?

Mobility/Control. What types of excavation, bag feeding, steering and control systems will be required? What analogs and operational hardware/software systems exist? Will basic new systems technology be required?

Power. What power sources and/or limitations are likely for lunar applications? How will available power options influence overall system design and operation? How much power will be required?

CONCEPT ELEMENTS AND FEATURES

The Soil-PAC concept embodies three system elements: an excavation device; a bagging device; and a mobility/control device.

The Excavation Device.

The excavation device should be designed to scoop or auger regolith at controlled depths and in sufficient quantities to satisfy practical production requirements. Design emphasis should be placed upon simplicity and reliability using proven technology to the extent possible. Alternative types of soil excavating devices should be surveyed for potential Soil-FAC application. These devices should include auger and scoop approaches. Auger systems offer potential advantages of being able to transport soil directly into bags or crushers connected to electromagnetic/electrostatic separations as desired. They also offer deeper trenching capabilities than scoops, enabling more material to be collected from small sites with fewer passes. Scoop approaches are potentially applicable to larger, flatter material sites where adhesive qualities of soils offer a good angle of repose. (Soil on the Moon typically forms steeper slopes than on Earth due to better adhesion characteristics. and the fact that the lower gravity exerts less force to pull soil down and collapse furrows.) The excavation device should be assessed on the basis of soil moving capacity; versatility; soil separation options; and simplicity and durability.

Soil Moving Capacity. Enormous quantities of soil will need to be moved to provide enough material to provide adequate radiation and thermal shielding for safe and practical application. While not absolutely necessary, the same or similar excavator devices might also be used for intensive lunar mining operations. Accordingly, furrow depth and traction related requirements should be correlated with equipment mass and leverage efficiency.

Versatility. Site topography and soil conditions will vary widely at alternative lunar material resource sites. Variations will include flat vs. uneven conditions, loose vs. more densley packed conditions, and rocky vs. even/fine-grained soil conditions. System flexibility to adapt to these conditions should be addressed.

Soil Separation Options. Crushers and separators may be desirable as standard or optional equipment to enable tailoring of soil mixes to specific requirements for shielding. Crushers may also be desirable to facilitate adaptation to rocky site conditions and to be used in combination with separators for mining operations (e.g., selective removal of ilmenite for the oxygen production process).

Simplicity and Durability. Excavators will be required to provide continuous long-term service under extreme environmental conditions. Maintenance and repair will be difficult due to EVA requirements and spare parts inventory limitations. System evaluations must take these circumstances into account as key considerations.

The Bagging Device.

Containment of materials in bags will enable dense packing of particles to optimize radiation shielding benefits. It also permits for ease of handling and efficient stacking geometries not possible with loose material, and will control dust during construction. Bags can later be removed/reconfigured to accommodate facility changes and growth. The bagging system should be sized for convenient handling and design to facilitate automation. Alternative bagging concepts should be identified through a survey of commercial/industrial analogs with an emphasis upon systems that provide high levels of automation for material insertion, packing density control and closure. Concept designs should include individual or tear-off sacks, continuous or segmented tubes and wrap-around/baling approaches. The systems should be assessed on the basis of automation capacity; servicing simplicity; and bag offloading.

Automation Capacity. Systems will need to provide continuous long-term container feeding with minimum human intervention for resupply or adjustments. Automation provisions must offer reliable means to securely seal bags when desired packing density has been achieved.

Servicing Simplicity. The system must be reliable and offer a large bag supply capacity to minimize EVA requirements.

Bag Offloading. The system must offload processed Soil-PACs in a manner that will avoid damage and facilitate convenient retrieval for use.

The Mobility/Control Device.

The excavation and bagging systems should be incorporated into a prime mover which provides power, tracking and control systems to achieve a high level of automation. Programming flexibility, operational reliability and minimization of human intervention requirements should be given paramount importance.

Prime Movers. Candidate vehicles to provide programmable transport can be expected to include tracked rovers, wheeled "trucks", and winch-pulled "sleds". Evaluation emphasis should be placed on load capacities, terrain adaptability, traction (if relevant), and automated "steerability".

Guidance Systems. Prime mover routings can potentially be directed by teleoperated steering devices, electronic tracking sensors and other means. Integrated or separate control systems must also be provided to maintain desired excavation furrow depth and speed. An emphasis must be place upon system reliability.

Power Systems. Power supply, transmission and conversion alternatives should be correlated with other candidate systems options and their respective requirements to the extent possible.

In general, a preliminary design concept for an automated regolith excavating and bagging process should incorporate key design considerations of simplicity, reliability and ease of maintenance; overall system capacity and efficiency in relation to equipment size and weight; use of proven technology where possible; and adaptability to varying site conditions and production requirements.

REFERENCES

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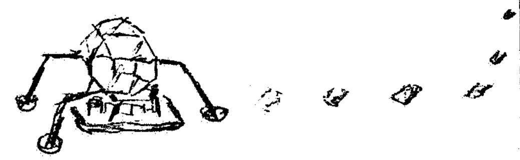
APPENDIX I



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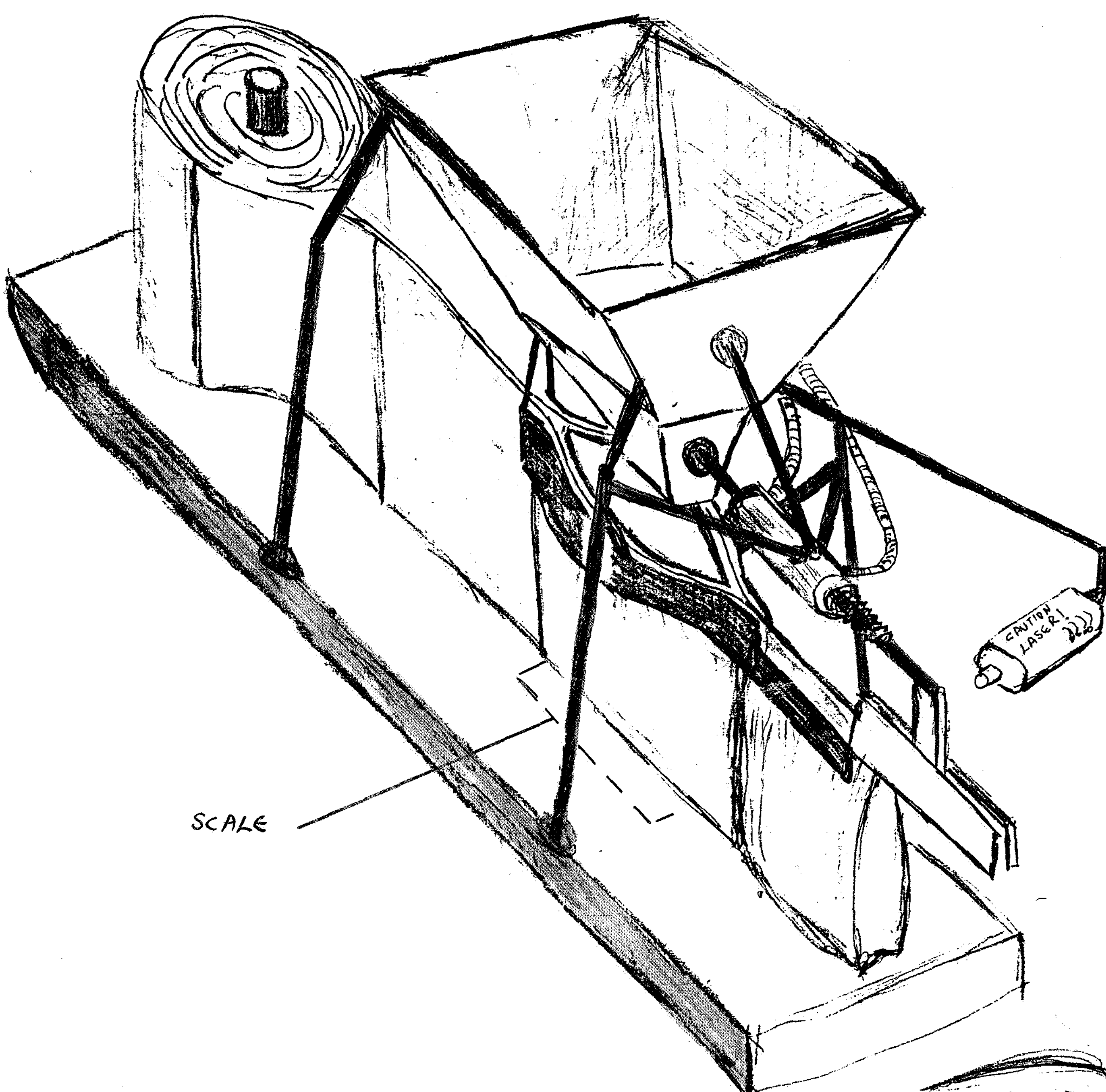
ARRANGEMENT OF HOPPER AND BAGS.



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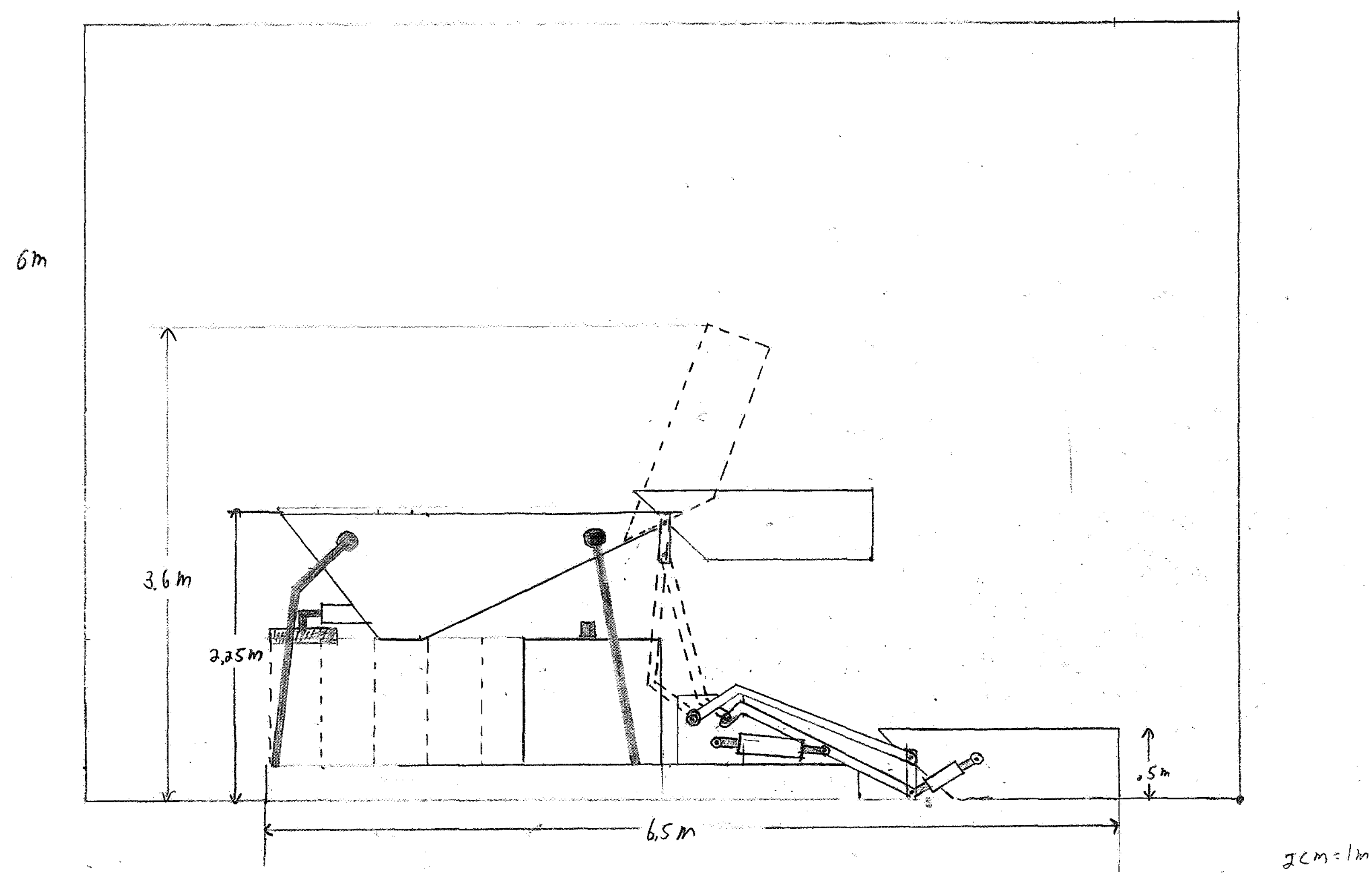

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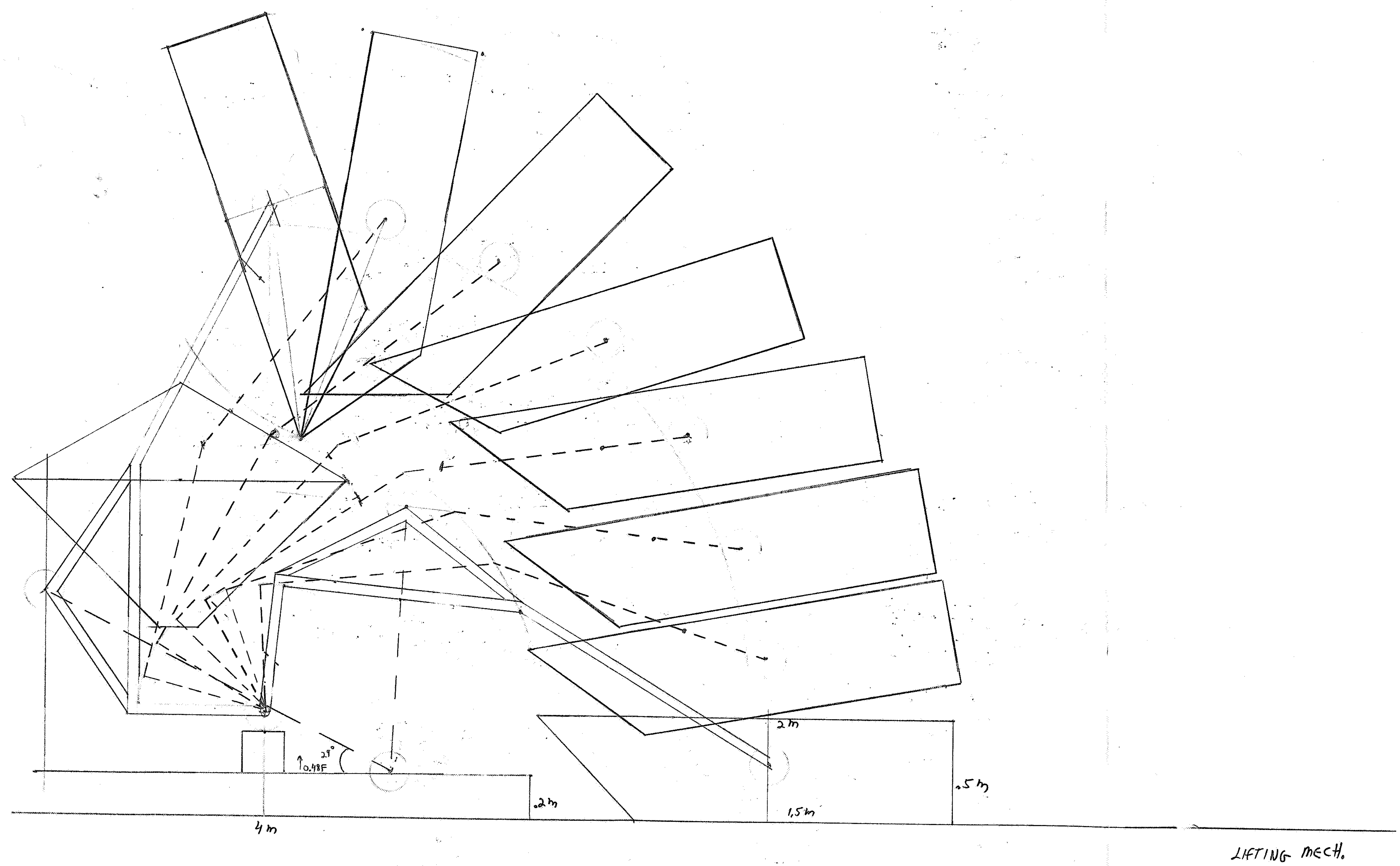
FOLDOUT FRAME 2.



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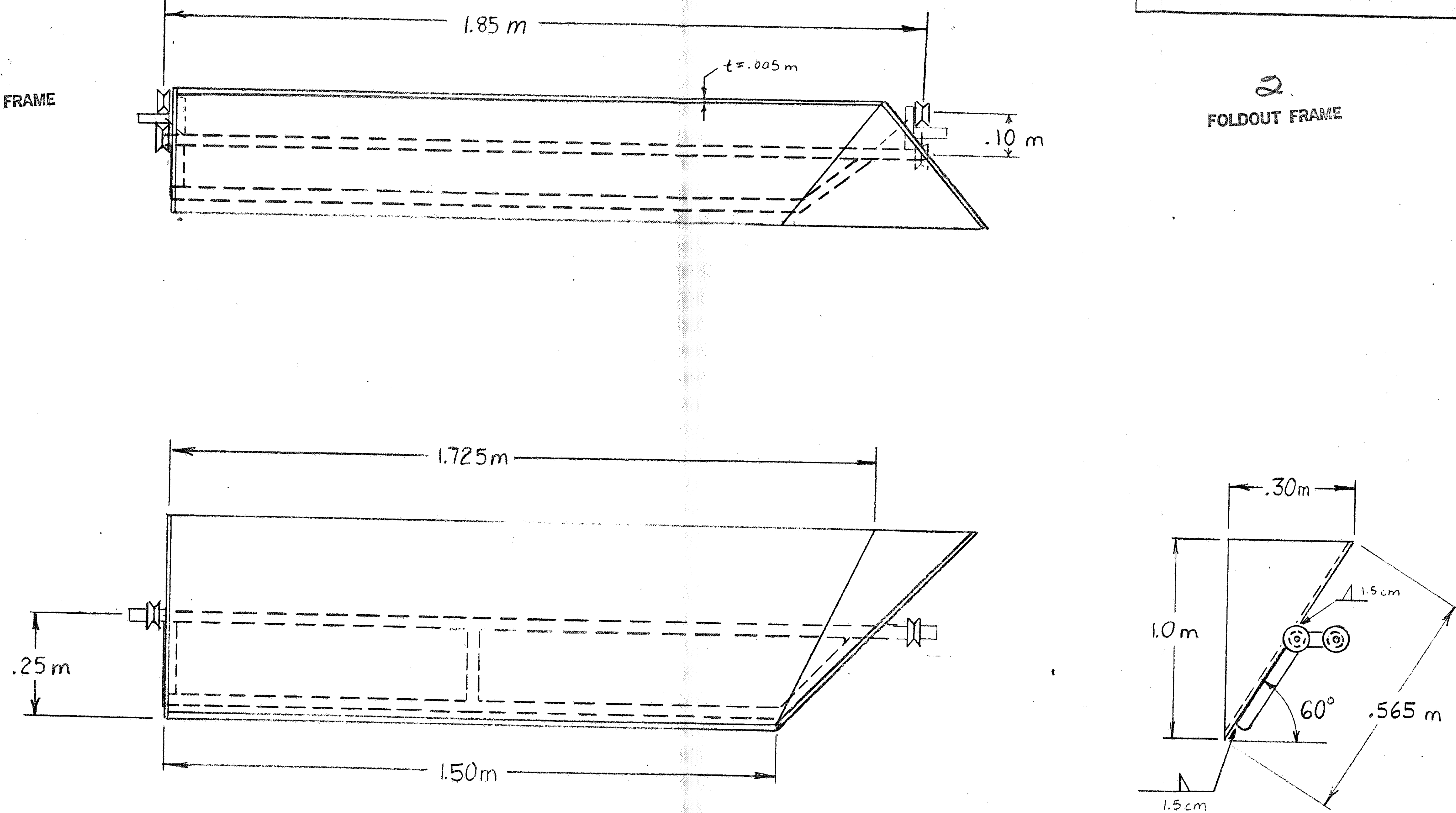

TUBING WEIGHT: 180 N= 40.5 lb	
SHEET WEIGHT: 328 N ≈ 74 lbs	

MATERIAL: AL-A97175	DESIGNED: J. IMPEDUGLIA
SCOOP/SUPPORT ASSM.	SOIL BAGGER

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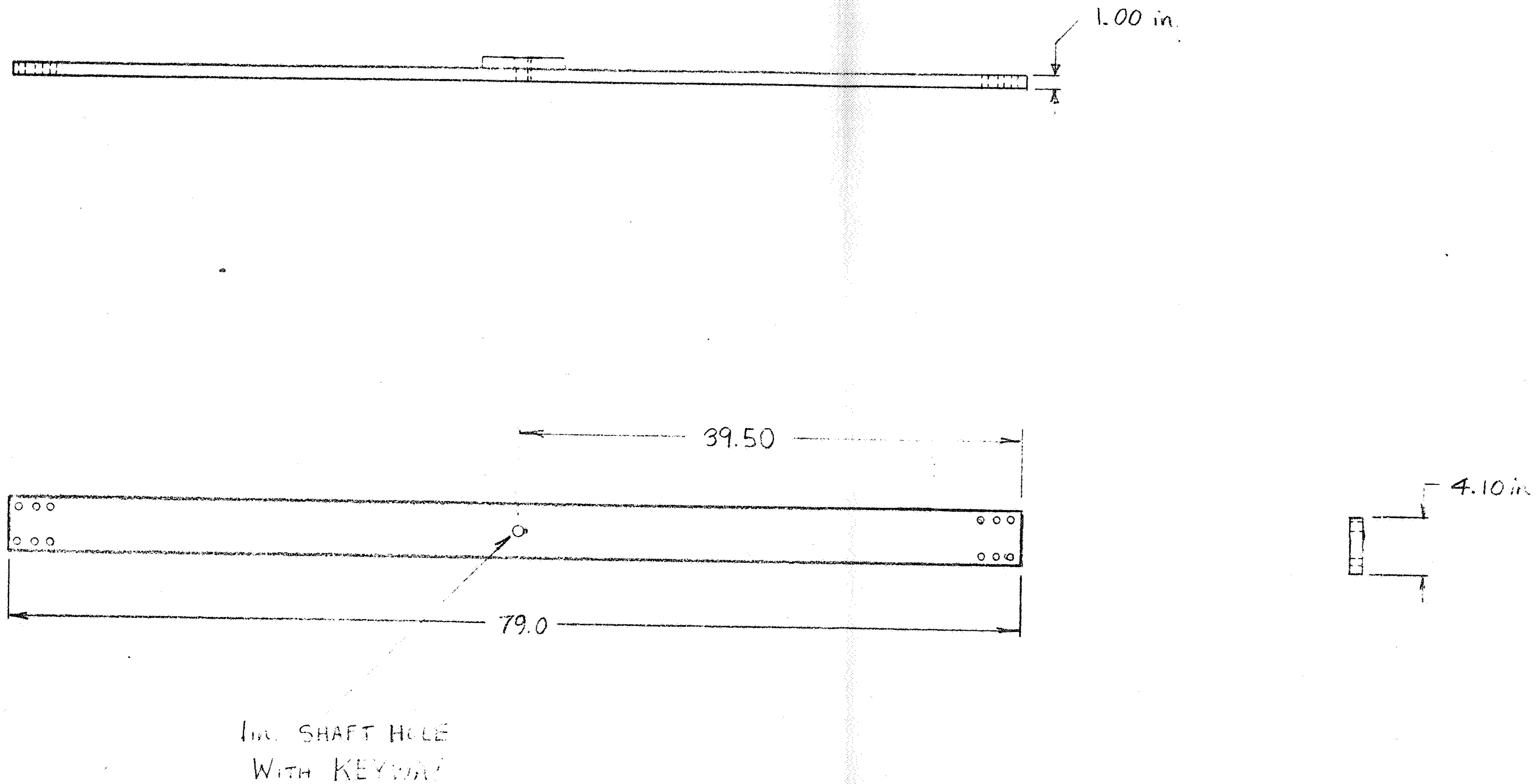

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WGHT: 6 lbs	FRAME SIDE SUPPORT	SOIL BAGGER

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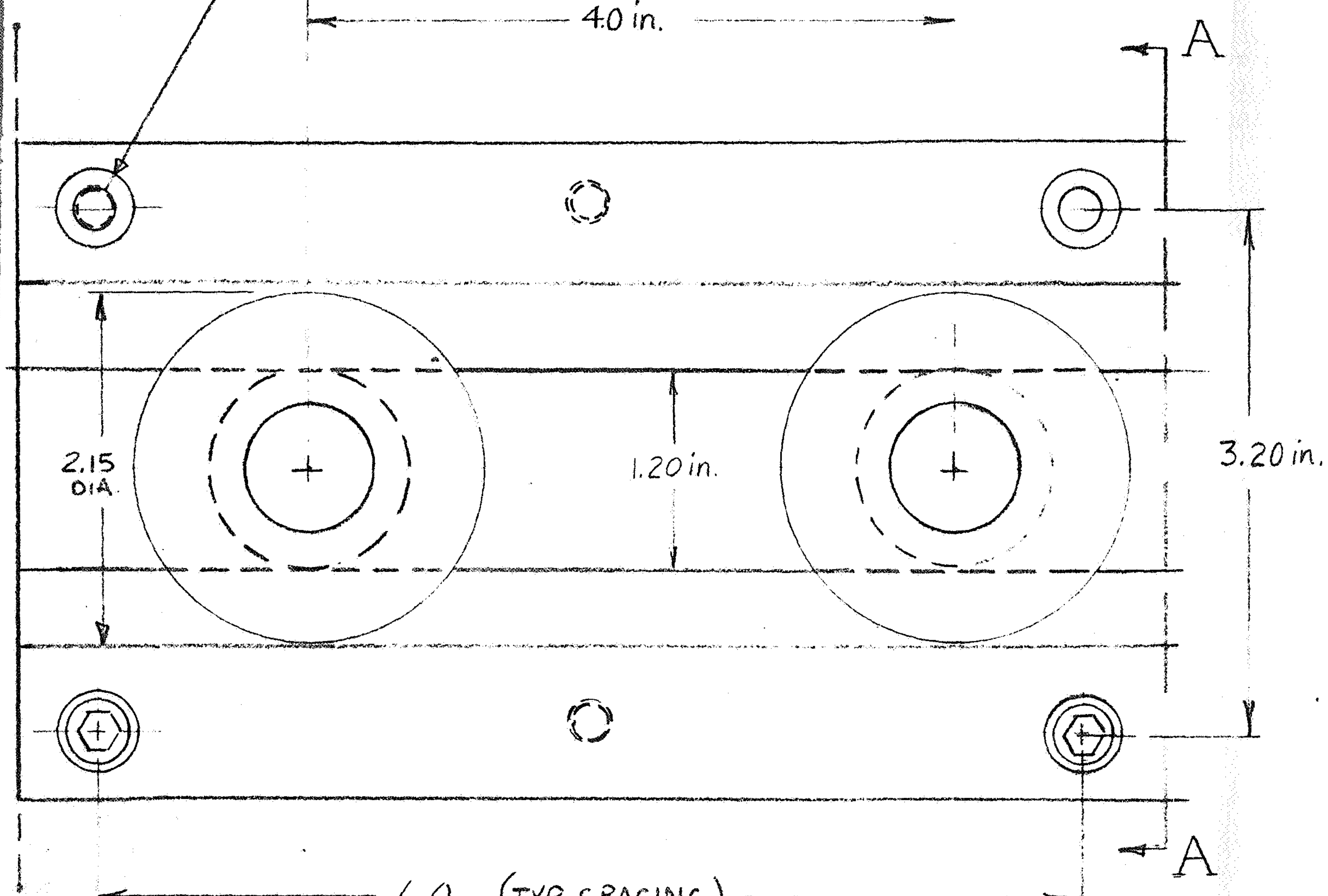
DWG. 2

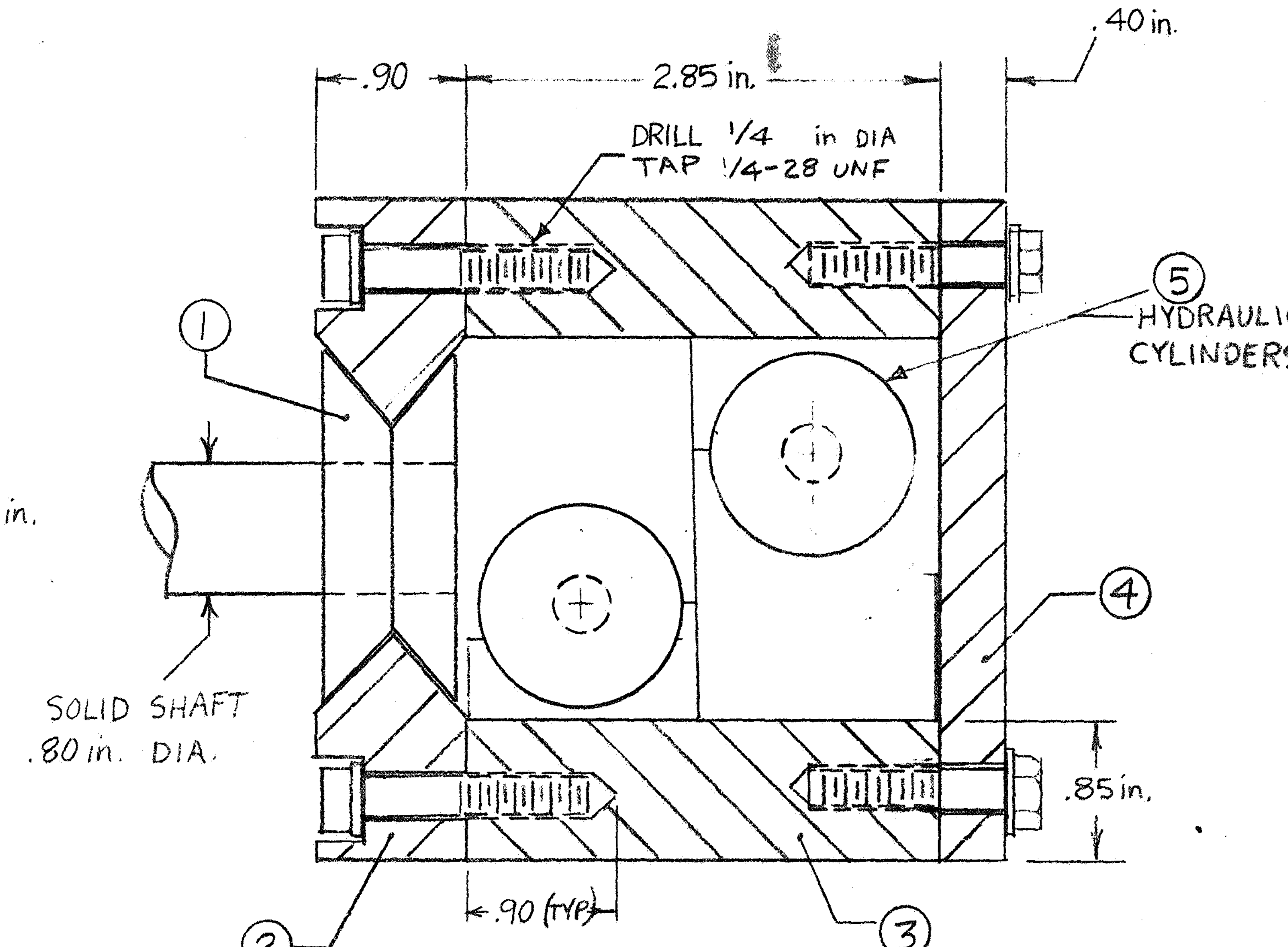
FULL SCALE

CROSS-SECTION VIEW OF SCOOP MECHANISM FRAME ASSEMBLY

1. FOLDOUT FRAME

2. FOLDOUT FRAME





VIEW AA

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